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and Space Administration

Scientific and Technical
Information Branch

SUMMARY

A new technique for fabricating uniform thin-wall metallic heat-transfer models is described. Two 6- by 6- by 2.5-in. tiles were fabricated to obtain local heat-transfer rates. This process is not limited to any particular geometry and results in a seamless thin-wall heat-transfer model which uses a one-wire thermocouple to obtain local "cold-wall" heat-transfer rates. The most important factors in the fabrication process are the cleaning and activating of the surfaces for plating. Also, after the plating is complete, the mandrel must be melted slowly to prevent thermal expansion of the mandrel from overstressing the Niculoy 22 tile surface. The tile is relatively fragile because of the brittle nature of the plating material and the structural weakness of the flat-sided configuration; however, a method was developed and used for repairing a cracked tile. The model fabrication and the test program were successful, and this fabrication technique is a viable option for highly detailed heat-transfer models, especially configurations that do not carry significant bending loads.

INTRODUCTION

The Space Shuttle thermal protection system (TPS) is an arrangement of discrete tiles separated by gaps (ref. 1). This arrangement creates the potential for high localized heating on the tiles because of flow penetrating into the gaps between the tiles. In figure 1, two regions of potential high heating are indicated on a test model array of simulated tiles. Since the TPS tile gaps on the Shuttle are oriented at an angle to the flow (nominally 45°), intense localized heating can occur at the upstream surface corner and at a location where a gap terminates at its intersection with another gap. Detailed heat-transfer data are required to determine the peak localized heating rates. Past investigations (refs. 2 to 4) have used formed metallic thin-wall tiles to simulate arrays of TPS tiles and to obtain local heat-transfer rates. These formed tiles were fabricated from a single sheet of metal, bent along the top surface edges and then welded at the sidewall joints. The tile was instrumented by spot welding standard two-wire thermocouples at the desired locations. When a high density of instrumentation is required with this technique, difficulties exist in (1) accurately knowing thermocouple locations, especially on edges and corners, (2) obtaining uniform thicknesses on edges and corners, and (3) knowing material properties at weld joints.

The NASA Johnson Space Center (JSC) had experimented with an electroless-plating technique, using a nickel alloy (ref. 5), that could be used to fabricate a uniform thin-wall tile; however, considerable advancement of the technique was required for the present application. Electroless plating is a process based on the autocatalytic reduction of nickel, copper, and phosphorus cations at elevated temperatures (190°F to 200°F) by means of hypophosphite anions in aqueous solution over a pH range of 4 to 5 (refs. 6 and 7). In this new application, the instrumentation (fig. 2) was incorporated as an integral part of the process and consisted of 256 one-wire thermocouples. The thin-wall tile was formed by electrolessly plating Niculoy 22[1] nickel-copper alloy (1 percent copper, 12 percent phosphorus, and 87 percent nickel) over a

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[1]Niculoy 22: Registered trademark of Shipley Company, Inc.

metal mandrel in which the thermocouples had been placed. After being plated to the desired thickness, the mandrel was melted to leave a thin-wall shell with the desired instrumentation precisely located. This method allows for the accurate placement of a large number of thermocouples in a small area. The resulting thin-wall shell is seamless, with a uniform thickness eliminating the previously mentioned difficulties. Because of the characteristics of electroless plating, complex geometries with small radii can be plated with a uniform thickness.

This report describes the process used to fabricate a thin-wall tile which simulates a Shuttle TPS tile; however, the technique is not limited to a particular geometry. The tiles produced by this process were successfully used to obtain local heat-transfer-rate distributions not obtainable by conventional methods (ref. 4). This report also covers problems encountered during the tile fabrication and the durability of the tile.

DESIGN CONSIDERATIONS

The investigation of gap heating associated with the Space Shuttle TPS tiles has been an ongoing program at the Langley Research Center. To obtain more detailed heat-transfer distributions on the tile system, a model simulating the TPS tile array was designed for aerothermal tests in the Langley 8-Foot High-Temperature Tunnel. Many design factors had to be considered. These factors included model geometry, wind-tunnel loads, instrumentation location and technique, heat-transfer measurement technique, data reduction technique, and tile and mold material properties.

The Shuttle tile geometry is nominally 6 in. square, and the thickness varies according to the expected heat load. In order to use equipment from previous test series, the instrumented tile for this investigation was designed to be approximately 6 by 6 by 2.5 in. Very detailed heat-transfer measurements in small regions on the tile, as well as overall heat-transfer distributions, were required. The instrumentation density necessary to determine the large gradients and peak localized heating eliminated the use of heat flux gages; therefore, the thin-wall heat-transfer technique using a one-wire thermocouple technique was chosen. For this technique, the model skin completed the thermocouple electrical circuit, and the convective heat load was calculated from the thermocouple temperature-rise rate (energy stored in the skin). The required thermocouple distribution with concentrations at the upstream tile corner and at a point where two gaps intersect is shown in figure 2. These areas were chosen for concentrated thermocouples because they were known areas of high localized heating. Constantan thermocouple wire was used because the thermoelectric properties of the Niculoy 22/constantan thermocouple produce an output (fig. 3) within 2 percent of the output of a standard copper/constantan thermocouple (ref. 5). The wire diameter of 0.005 in. was determined by experimentation to be strong enough for this application and by thermal analysis to be small enough to eliminate most of the heat conduction down the thermocouple wire that would affect the heat-transfer-rate measurements.

The thin-wall technique requires a uniformly thin wall and constant material properties throughout the tile. A Niculoy 22 electroless-plating process could provide these requirements; however, structural strength problems are encountered because of the brittle nature of the Niculoy 22. During wind-tunnel testing, the model must withstand pressure loadings imposed by the hypersonic stream as well as the heat input to the model. Three-point bending tests were used to determine that a Niculoy 22 wall thickness of 0.025 in. would be adequate to support the hypersonic

aerodynamic loads. Thermal analysis showed that a wall thickness of 0.025 in. was also suitable for a thin-wall heat-transfer model.

Few material properties for the Niculoy 22 were available from the manufacturer. Therefore, all required material properties were measured by the Instrument Research Division of the Langley Research Center. Density and specific heat were measured on many sample platings and were found to be isotropic with values of approximately 499 lbm/ft^3 and 0.12 Btu/lbm-°F, respectively. The specific heat was measured with a differential scanning calorimeter using a synthetic sapphire as a reference material, and the density was measured by the method of Archimedes. Niculoy 22 loses ductility at temperatures above 500°F.

Several molds and a mandrel were required for the fabrication technique. Materials were chosen on the basis of their material characteristics and their usable temperature ranges. The temperature ranges were important because of the need for strength at the elevated temperatures where metal casting and electroless plating occur. The most critical material selection was for the mandrel upon which the thin-wall tile was plated. The material had to have a melting temperature higher than the electroless-plating temperature but low enough to melt without damaging the plated tile wall structure. Other material considerations were formulated during the finalization of the fabrication technique and will be discussed in upcoming sections.

FABRICATION PROCESS

An electroless-plating technique first used by the Johnson Space Center (JSC) met the required needs; however, only small models with limited instrumentation were attempted. To fabricate the thin-wall tile discussed in this paper, considerable extension of that technology was required. After several trial attempts, a new fabrication process was developed. The new process was designed to plate a nickel alloy, Niculoy 22, over a Cerrotru[2] alloy mandrel containing precisely located one-wire thermocouples and then to remove the mandrel by melting the Cerrotru. This process resulted in an instrumented freestanding thin-wall shell. Two tiles were fabricated by this process. The fabrication process is long and complex; hence, an outline of the steps required for the fabrication is given below. The steps are described in detail in subsequent sections.

I. Mold Preparations

1. Precision machine male and female aluminum molds to produce Stycast[3] epoxy resin shell with cast holes precisely located for instrumentation.

2. Instrument Stycast shell with 256 one-wire constantan thermocouples (0.005-in. diameter).

3. Cast Cerrotru mandrel in Stycast shell.

4. Break Stycast shell away from Cerrotru mandrel to leave mandrel with thermocouple wires extending from its surface.

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[2]Cerrotru: Registered trademark of Cerro Sales Corporation.
[3]Stycast: Registered trademark of Emerson & Cuming, Inc.

II. Plating Procedures

1. Seal Cerrotru mandrel with copper strike.

2. Further seal mandrel with Niculoy 22 strike.

3. Plate Niculoy 22 to thickness of 0.0125 in. over sealed mandrel.

4. Clip and polish thermocouple wire tips extending from mandrel until they are flush with surface.

5. Plate Niculoy 22 to total thickness of 0.025 in. over the mandrel.

III. Mandrel Removal

1. Remove Cerrotru mandrel from Niculoy 22 tile by melting.

2. Clean inside of Niculoy 22 tile with acid and abrasive blasting.

Mold Preparations

In order to form the Cerrotru mandrel, a mold had to be formed that could be easily removed from the Cerrotru. A plastic material called Stycast was selected for the mold because Cerrotru would not stick to the Stycast. When properly cured, Stycast also maintains its strength at the melting temperature of Cerrotru and provides a smooth surface. Holes to anchor thermocouple wires in the Cerrotru mandrel could also be cast in Stycast. A thin Stycast shell (0.125 in. thick) was required to cast the Cerrotru mandrel, so that the Stycast could be easily broken away from the Cerrotru without damaging the instrumentation or scarring the surface of the Cerrotru.

Inner and outer aluminum molds were required to cast the thin Stycast shell. Aluminum was selected for these molds because of its availability and machinability. The outer aluminum mold (fig. 4) served as the outer container for the liquid Stycast. The inner aluminum mold (fig. 5(a)) was the most critical part with regard to surface finish and instrumentation location. The inner mold was machined to the desired tile dimensions minus the desired 0.025-in. tile wall thickness with an accuracy of ±0.005 in. All inner mold edges were machined to a radius of 0.075 in. The inner mold was then polished to the desired surface finish. Holes were drilled through the inner mold, and pins were inserted as shown in figures 5(a) through 5(c) to allow for instrumentation. Since drilling of 0.005-in-diameter holes (thermocouple wire diameter) would be extremely difficult, 0.017-in-diameter holes were drilled. These holes were located within ±0.005 in. of the desired location by referencing two inner mold side walls. Then, with the use of a digital readout on a drilling machine, the holes were located and drilled. Measurements made after the drilling showed all holes were located properly. Pins were then installed in these holes to provide the holes in the Stycast for later placement of the thermocouple wires. When the inner and outer aluminum molds were assembled (fig. 6), the pins protruded through the inner mold to the outer aluminum mold. All surfaces of the molds and pins were sprayed with a release agent[4] to prevent the Stycast from stick-

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[4]MS-122 Release Agent Dry Lubricant: Manufactured by Miller-Stephenson Chemical Co., Inc.

ing. Figure 7 shows the inner and outer aluminum molds fully assembled and ready to receive the Stycast. A funnel provided a large area for pouring the Stycast and a pressure head for even flow. The edge opposite the funnel was elevated to prevent air bubbles from being trapped on the flat surfaces.

The liquid Stycast mixture was prepared according to the directions of the manufacturer, except that after the Stycast had been thoroughly mixed, the mixture was exposed to a vacuum to eliminate air bubbles created by the mixing process. After most of the air bubbles had been removed, the mixture was slowly poured into the mold. The Stycast was then cured according to the directions of the manufacturer. After curing was completed, the pins were removed, and the molds were separated. This procedure resulted in a thin Stycast shell with holes at the desired thermocouple locations.

As stated above, the instrumentation holes were larger than the 0.005-in-diameter thermocouple wires. The holes were sized to accept a 0.017-in-diameter brass tube that had a 0.005-in. inner diameter. The insert in figure 8(a) shows a brass tube installed in a hole in the Stycast shell and a 0.005-in-diameter thermocouple wire inserted into the inner diameter of the brass tube. The brass tube and the thermocouple wire were secured on the outside of the Stycast shell with epoxy. Examples of the installation are shown in figure 8(a). The inside of the Stycast shell is seen in figure 8(b) with part of the instrumentation present.

Since the fabrication technique required that the Stycast shell be thin so that the shell could be broken away, a support structure for the shell was required, so that the shell would not break when the hot Cerrotru was poured into the shell. The Stycast support structure, shown in figures 9 and 10, was also used to support a filler block and a tube for thermocouple lead wire exits and later for mandrel support. By using a filler block (fig. 10), a smaller amount of the heavy Cerrotru material was required. Also, since the Cerrotru expands a small amount while solidifying, a rubber expansion seal was installed around the filler block.

During the fabrication development program, the Stycast was found to outgas when the hot Cerrotru was poured into the mold. This outgassing was eliminated by heating the Stycast shell in a vacuum furnace for 24 hours to a temperature equivalent to the melting temperature of Cerrotru. Figure 9 shows molten Cerrotru being poured into the Stycast shell. A thermocouple was inserted into the molten Cerrotru to monitor the temperature. The Cerrotru was held at its melting temperature for a short period of time, and then the temperature of the furnace was lowered slowly (approximately 20°F per hour) to prevent the Cerrotru from expanding and cracking the Stycast shell. After the Cerrotru had completely solidified, the thermocouple wires protruding from the backside of the shell were clipped, and the Stycast and brass tubes were broken away in small pieces. This was done with great care in order not to break the fragile thermocouple wires or scar the Cerrotru surface. The Cerrotru mandrel, shown in figure 10, was a demonstration mandrel and does not have all the thermocouples used in the actual test tiles. Figure 11 shows an actual mandrel with all the test tile thermocouples.

Plating Procedures

The electroless Niculoy 22 plating used for the thin-wall model had never been done on a large mandrel or on a mandrel of Cerrotru at JSC. The basic plating setup shown in figure 12 existed at JSC; however, a larger tank, more filtering, and more vigorous agitation were needed. Also, because plating times of 25 hours were

required to plate 0.0125 in. (one-half the final tile thickness), the plating solution had to be continually monitored and replenished. Problems encountered during the plating process are discussed in a later section.

The cleaning and activating of the mandrel were very important and had to be carried out precisely. The following procedure was used for cleaning, activating, and plating the Cerrotru mandrel:

1. Degrease mandrel in freon for 10 minutes.
2. Rinse in deionized water.
3. Degrease in ultrasonic freon tank for 5 minutes.
4. Rinse in deionized water.
5. Alkaline clean in Turco Aviation[5] cleaner at 180°F for 15 minutes.
6. Rinse in deionized water.
7. Activate surface on mandrel by immersing in 50 percent hydrochloric acid for 1 minute.
8. Rinse in deionized water.
9. Copper strike in Rochelle cyanide copper-plating solution for 3 minutes.
10. Rinse in deionized water.
11. Mask mandrel with Turco 5580-G[6] coating to prevent plating on unwanted areas.
12. Rinse in deionized water.
13. Immerse in Niculoy 22 plating strike bath for 1 hour.
14. Transfer without rinsing to Niculoy 22 plating tank and plate to a thickness of 0.0125 in.
15. Rinse in deionized water. Inspect and trim thermocouple wires.
16. Degrease in ultrasonic freon tank for 5 minutes.
17. Rinse in deionized water.
18. Alkaline clean in Turco Aviation cleaner at 180°F for 15 minutes.
19. Rinse in deionized water.

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[5]Turco Aviation: Registered trademark of Turco Products.
[6]Turco 5580-G: Manufactured by Turco Products.

20. Activate in 30 percent by volume sulfuric acid solution by the following method: Make anodic at 20 amp/ft^2 for 5 minutes, increase current density to 200 amp/ft^2, continue to anodic etch for an additional 2 minutes, and finally make cathodic at 200 amp/ft^2 for 3 to 5 seconds.

21. Rinse in hot deionized water.

22. Place in Niculoy 22 plating tank, touch plated nickel surface with a steel rod while placing mandrel into tank to start catalytic nickel plating, and plate to final thickness of 0.025 in.

23. Rinse in deionized water and dry.

This procedure results in an instrumented Cerrotru mandrel with a Niculoy 22 plate 0.025 in. thick.

Mandrel Removal

The Cerrotru mandrel had to be removed in order to use the thin-wall model for determining the heating rates. The mandrel was removed by slowly melting the Cerrotru in a furnace. Since the Cerrotru started melting first at the Cerrotru/Niculoy interface, the heavy Cerrotru mandrel had to be supported so that the delicate thermocouple wires would not be sheared at the interface. For that reason, the Stycast support structure (fig. 9) was used again to support the Cerrotru mandrel while it was melting. Once the Cerrotru had completely melted, it was poured from the Niculoy 22 thin-wall tile, and the tile was allowed to cool slowly. Figure 13 shows the interior of the tile after the Cerrotru had been removed. As can be seen from the photograph, a residue of Cerrotru remains that must be removed by an acid wash and abrasive blasting. Most of the Cerrotru residue was removed by immersing the tile in a 95 percent solution of sulfuric acid at 300°F for 3 to 4 minutes. By using a pencil abrasive blaster, the remaining residue was removed. The acid did not damage the thermocouple wire insulation or cause any measurable decrease in the thermocouple wire diameter. A completed model is shown in figure 14. The strip down the center of the tile (fig. 14(b)) is blueing that was used to mark the center of the tile. The insert shows the final instrumented thin-wall structure.

PLATING PROBLEMS

Several attempts were made at fabricating the tile before the fabricating technique was established. Most of the problems encountered during fabrication dealt with plating Niculoy 22 on a Cerrotru mandrel. The problems included plate thickness, cleaning and activating the plating surfaces, pitting and surface roughness, and delaminations.

Most applications for electroless nickel are for very thin surface finishes. This was the first known application for a freestanding plating of this thickness and size. The optimum temperature for Niculoy 22 plating is between 190°F and 200°F. Since the plating rate varies exponentially with temperature (ref. 6), the temperature must be closely monitored. At these temperatures, the plating rate for Niculoy 22 is 0.0005 in. per hour; therefore, 50 hours of plating time and almost constant supervision were required. In addition, the plating solution had to be checked often and continually replenished to make sure all constituents of the plating solution remained within the recommended limits. To ensure the proper plate

thickness, a piece of stock metal was placed in the plating solution and measured periodically to obtain plating rate and total thickness.

During the initial plating trials, pitting, surface roughness, and delamination were problems. To determine the cause of the pitting and surface roughness in the plated nickel, samples were evaluated by microscopic, metallographic, and scanning electron microscopic techniques. Through these evaluations, Cerrotru was found to be a catalytic poison to the Niculoy 22 plating solution. Cerrotru is 58 percent bismuth and 42 percent tin. Such catalytic poisons as tin, lead, sulfur compounds, and long-chain organic amines will cause defective deposits or poor adhesion (ref. 6). Figure 15 is a cross-sectional photomicrograph of a defective sample plating showing surface roughness, pits, and delaminations. Surface roughness was caused by inadequate solution agitation and filtration and decomposition of plating solution constituents. These problems were eliminated. Pitting was caused by particles in the solution adhering to the plate surface or by outgassing of entrapped cleaning solutions in the microscopic shrink cavities of the cast Cerrotru mandrel during plating. Figure 16(a) is a scanning electron microscopic (SEM) photograph (magnified 50 times) of the side view of a pit. After this pit was examined by SEM energy dispersion analysis of X-rays, it was found to contain particles containing tin and bismuth that had adhered to the plate surface. These tin and bismuth particles were the probable cause of the pit. Figure 16(b) shows these particles magnified 500 times in the bottom of the pit. Filtering the plating solution helped but did not eliminate the problem. The Cerrotru was the source of the contaminants, but the Cerrotru was required because of its melting temperature range compatibility with the plating temperature. To obtain a satisfactory plating solution, the particles of tin and bismuth had to be eliminated from the plating solution. Copper is a constituent of Niculoy 22 and can be electroplated to a very thin layer. Copper, aluminum, stainless steel, and brass are some of the most important common materials suitable for direct electroless nickel plating. Therefore, the Cerrotru mandrel was sealed with a very thin layer of copper electroplated from a Rochelle solution. Figure 11 shows the Cerrotru mandrel after the copper strike. The pits in the Niculoy plate, caused by the entrapped cleaning solutions, were eliminated by more careful adherence to the cleaning and rinsing techniques.

The delaminations shown in figures 15 and 16(a) were caused by improper cleaning and activating of the surface prior to entering the plating bath and by in-use decomposition of the plating solution. This resulted in poor bonding of newly deposited metal. In one of the delamination areas, a layer of copper between the laminates was identified by X-ray chemical spectroscopy. This copper layer was probably caused by a decomposition of the Niculoy 22 solution and an adherence of the decomposed copper to the plated surface. Delaminations cause a structural weakness and are a serious structural problem. The delaminations were eliminated by close adherence to the recommended plating procedures.

A cross-sectional photomicrograph of a successful plating magnified 200 times is shown in figure 17. The photomicrograph shows minimal pits and no delaminations. The black parallel lines are striations and not delaminations. Striations (ref. 7) are arrays of parallel lines or plies, caused from periodic variations of the phosphorus content of the plating solution. These striations are not considered to be structurally weakening. They were visible on sectioned specimens which were polished and electrolytically etched in an aqueous 10 percent solution of oxalic acid.

TILE DURABILITY

The instrumented heat-transfer tile fabricated from the described electroless nickel-plating process was placed in the center of an array of other metallic tiles (see fig. 18) and tested in the Langley 8-Foot High-Temperature Tunnel (ref. 8). The tile was exposed to 26 tests at a nominal Mach number of 7, a nominal total temperature of 2840°F, and a free-stream dynamic pressure of 2.1 to 9.0 psia. Model exposure times were up to 2 seconds. The pressure differential across the tile wall thickness was minimized during the tests by venting the cavity behind the model to the free-stream pressure. The tile showed good durability until it was heated very rapidly and passed its temperature limit of 500°F. In one of the high-localized-heating regions, the temperature-rise rate was 500°F per second (fig. 19) and surpassed the temperature limit by 200°F. This rapid heating set up high thermal stresses in the tile, which resulted in the tile cracking. A method of repairing the tile was devised; however, after being repaired, the tile was inherently weaker. The tile was repaired by soft soldering (50 percent tin, 50 percent lead) the cracks together. The repaired tile underwent subsequent wind-tunnel exposures. After numerous exposures, the tile was damaged beyond repair; however, some of the repaired cracks remained intact. (See fig. 20.) These cracks were not layered as had been experienced when the tile wall contained delaminations. This method of repair only affected the thermocouples near the repaired cracks. Thermocouple wires that have been broken away from the tile inner surface were also repaired by spot welding the wire to the appropriate location. Because of the brittle nature of the Niculoy 22, great care had to taken when installing the model in a test fixture. Overtorquing attachment bolts can cause cracks in the model structure.

The model fabrication and the test program were successful, and this fabrication technique is a viable option for highly detailed heat-transfer models, especially configurations that do not carry significant bending loads. Additional work is required to optimize configurations with large flat areas. One possible solution for the large flat areas would be to form the model on a low-thermal-conductivity material which could also provide structural support. The present technique would be more suitable for a wind tunnel with less severe test conditions.

CONCLUDING REMARKS

A new technique for fabricating uniform thin-wall metallic heat-transfer models is described. Two 6- by 6- by 2.5-in. tiles were fabricated and were successfully used to obtain local "cold wall" heat-transfer-rate distributions not obtainable by conventional methods. This technique is an extension of an electroless nickel-plating technique for fabricating small models that was developed under a Johnson Space Center contract. This process is not limited to any particular geometry and results in a seamless thin-wall heat-transfer model which uses a one-wire thermocouple to obtain local heat-transfer rates. The most important factors in the fabrication process are the cleaning and activating of the surfaces for plating. Also, the mandrel must be melted slowly to prevent thermal expansion of the mandrel from overstressing the Niculoy 22 tile surface. The tile is relatively fragile because of the brittle nature of the material and the structural weakness of the flat-sided configuration. A method was developed and used for repairing a cracked tile. The model

fabrication and the test program were successful, and this fabrication technique is a viable option for highly detailed heat-transfer models, especially configurations that do not carry significant bending loads.

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July 5, 1984

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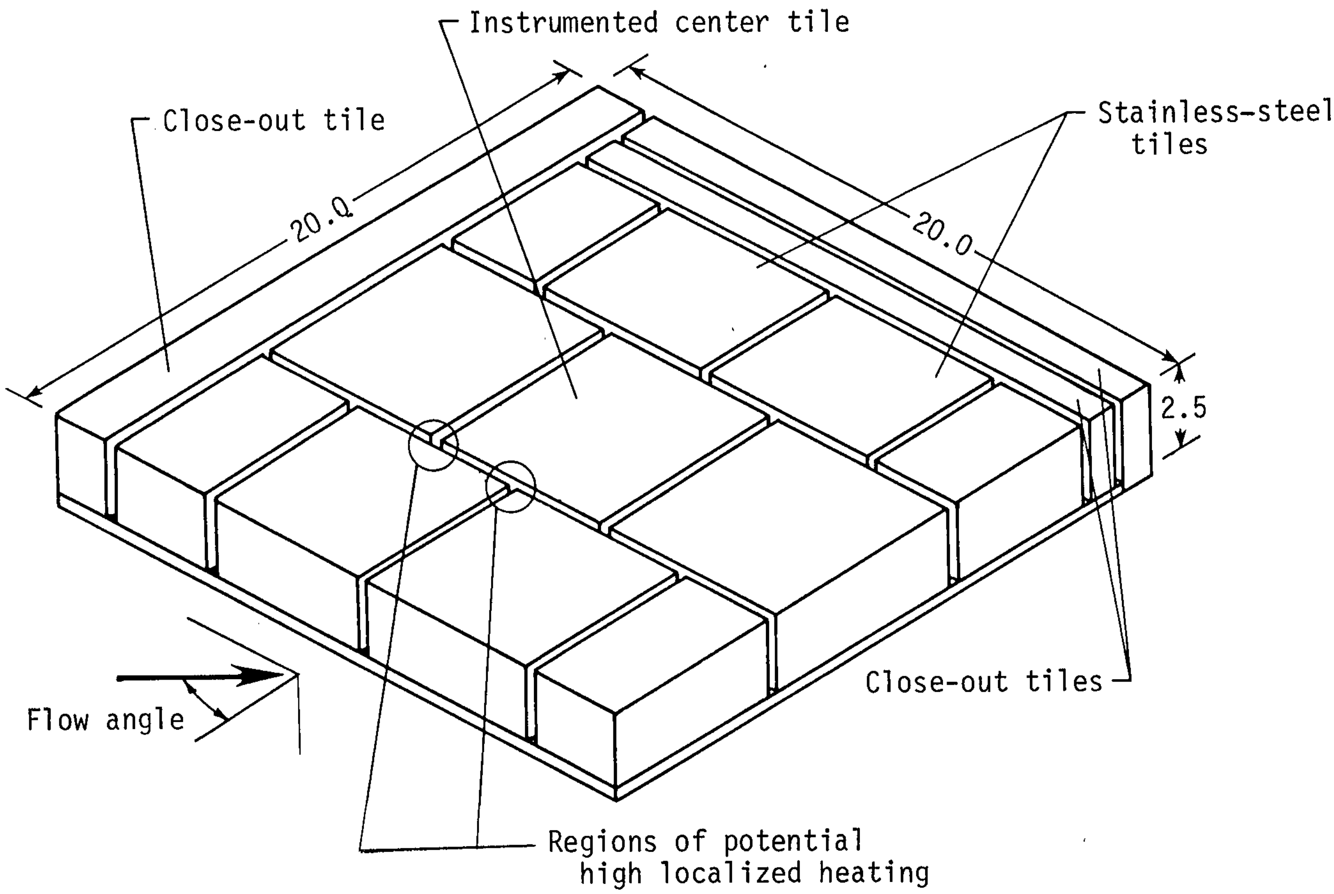

Figure 1.- Test model of simulated TPS tile array. Dimensions are in inches.

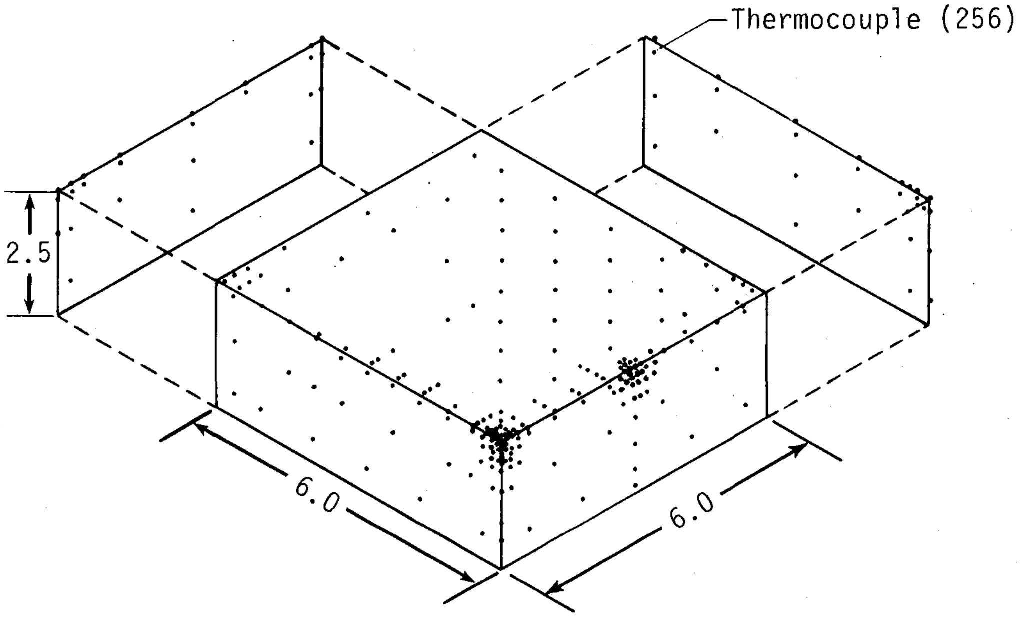

Figure 2.- Center tile configuration showing instrumentation distribution. Dimensions are in inches.

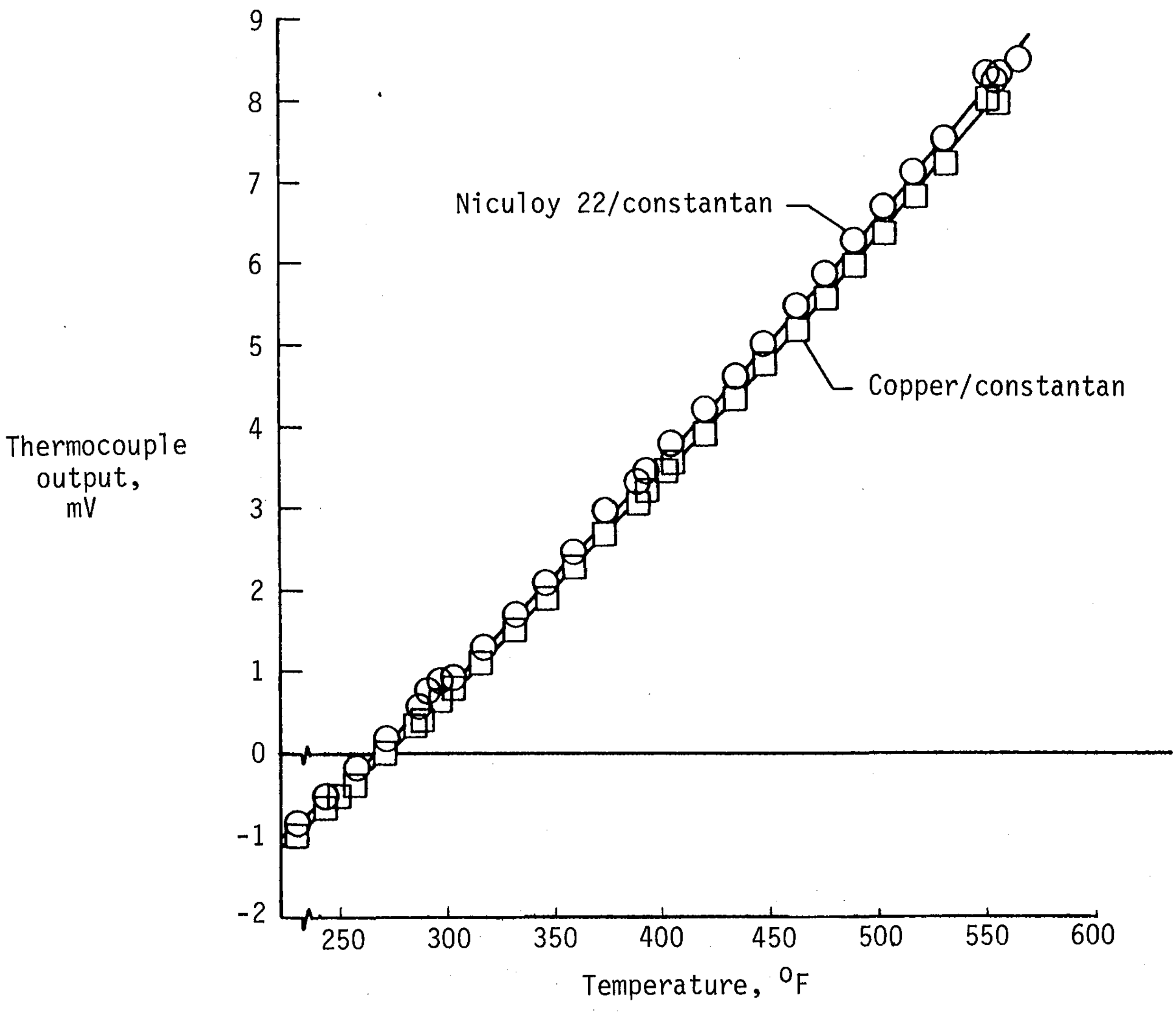

Figure 3.- Comparison of calibrations for Niculoy 22/constantan and copper/constantan thermocouples.

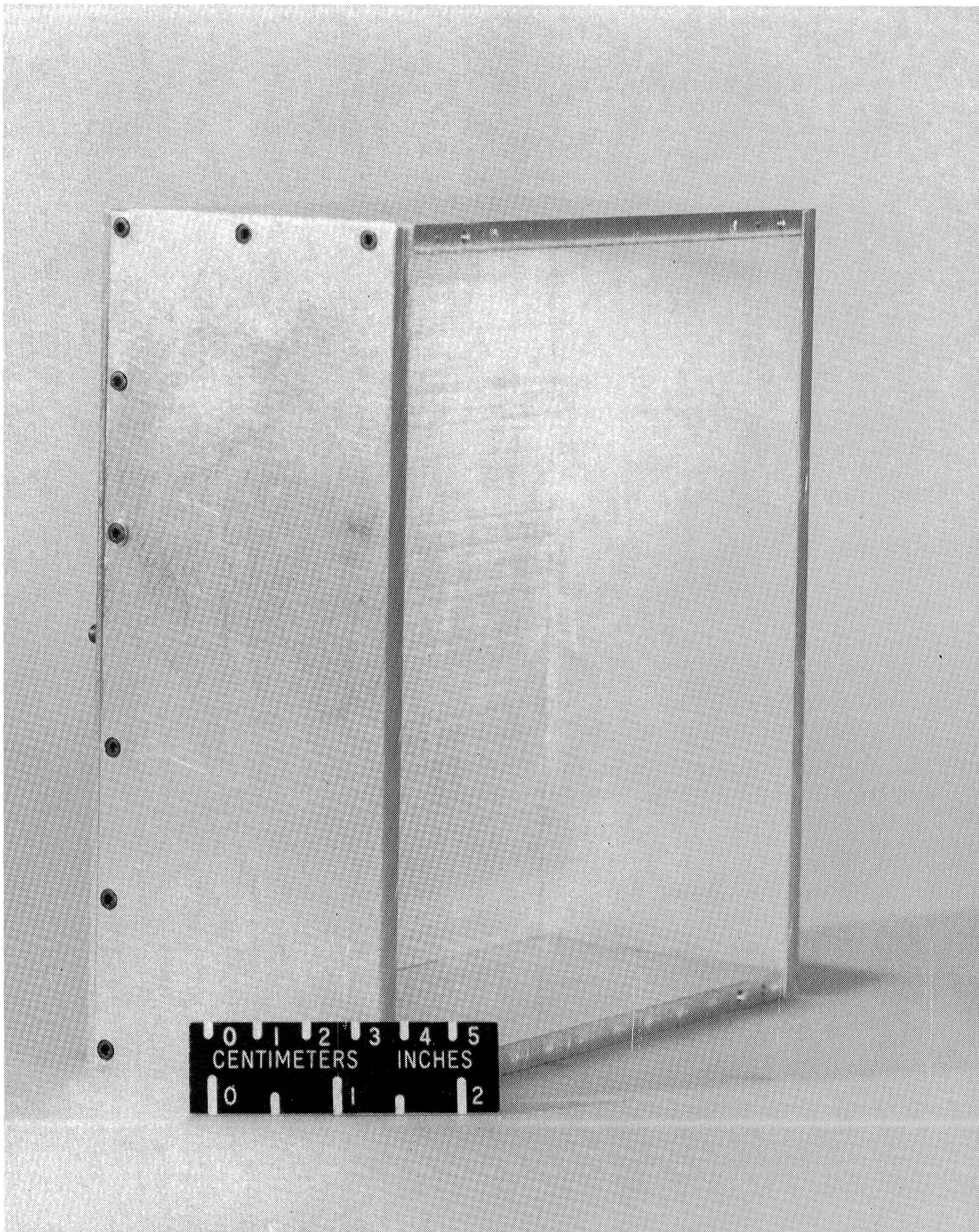

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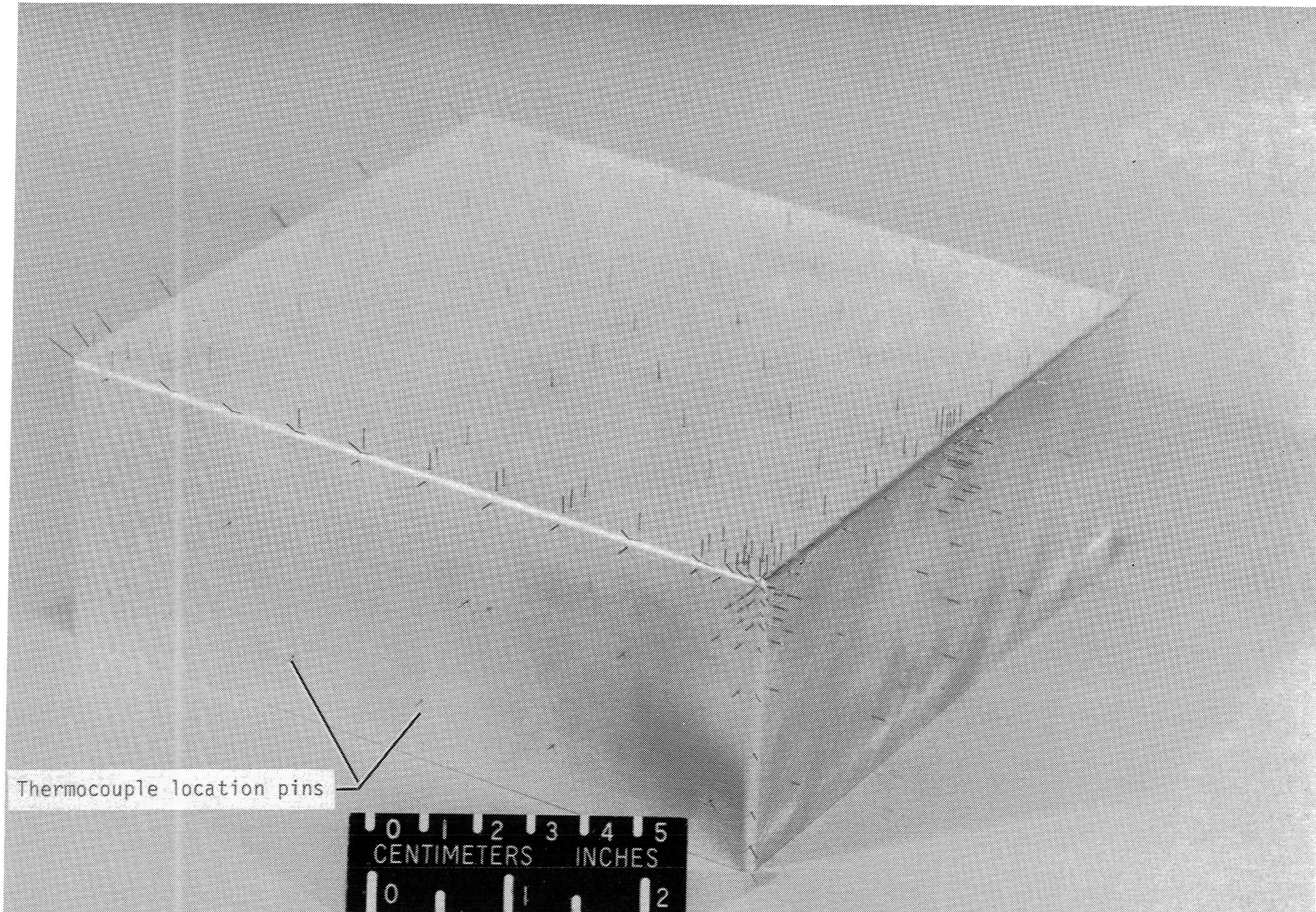
Figure 4.- Outer aluminum mold.



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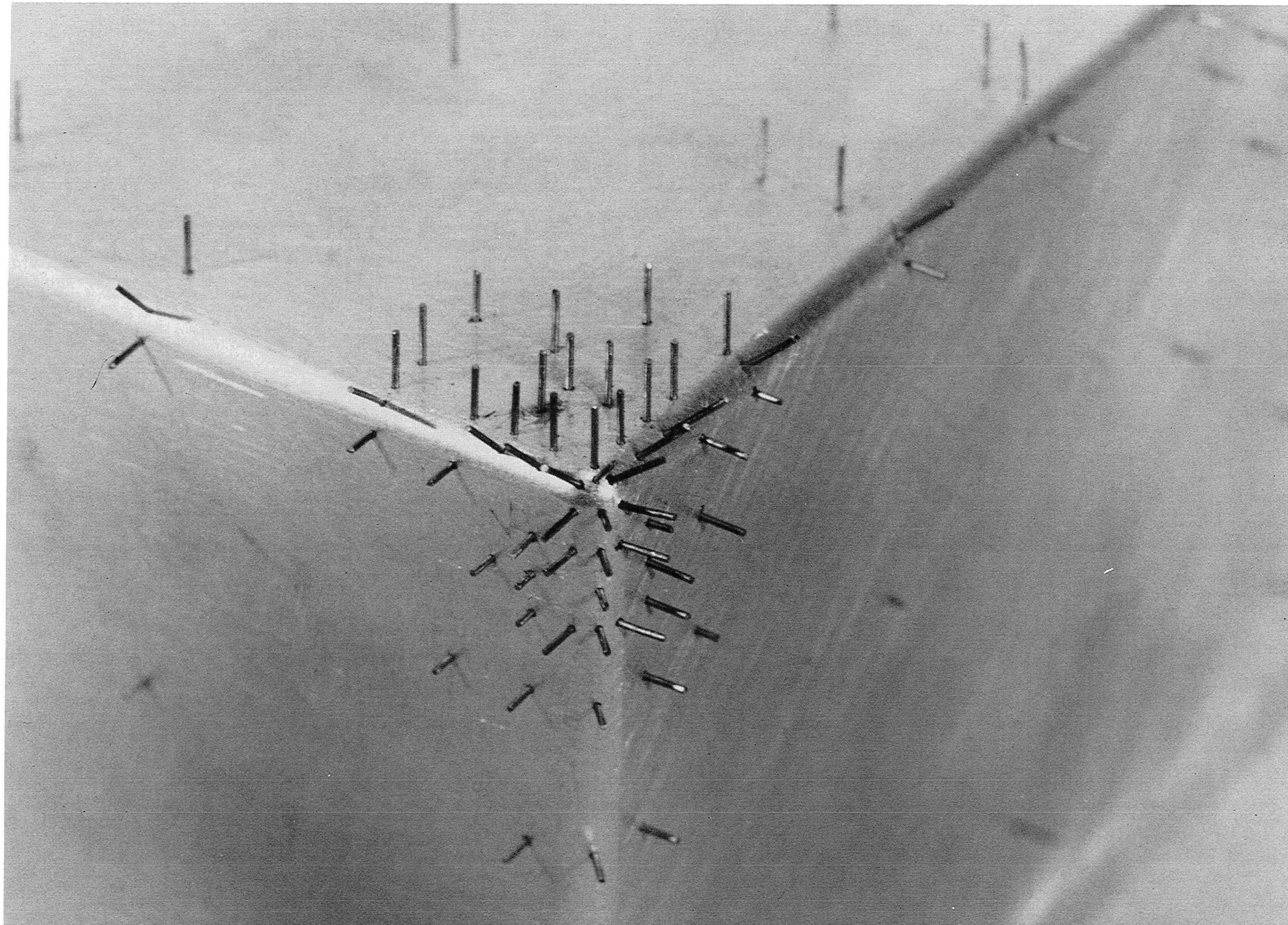
(a) Overall view.

Figure 5.- Inner aluminum mold showing thermocouple locations.



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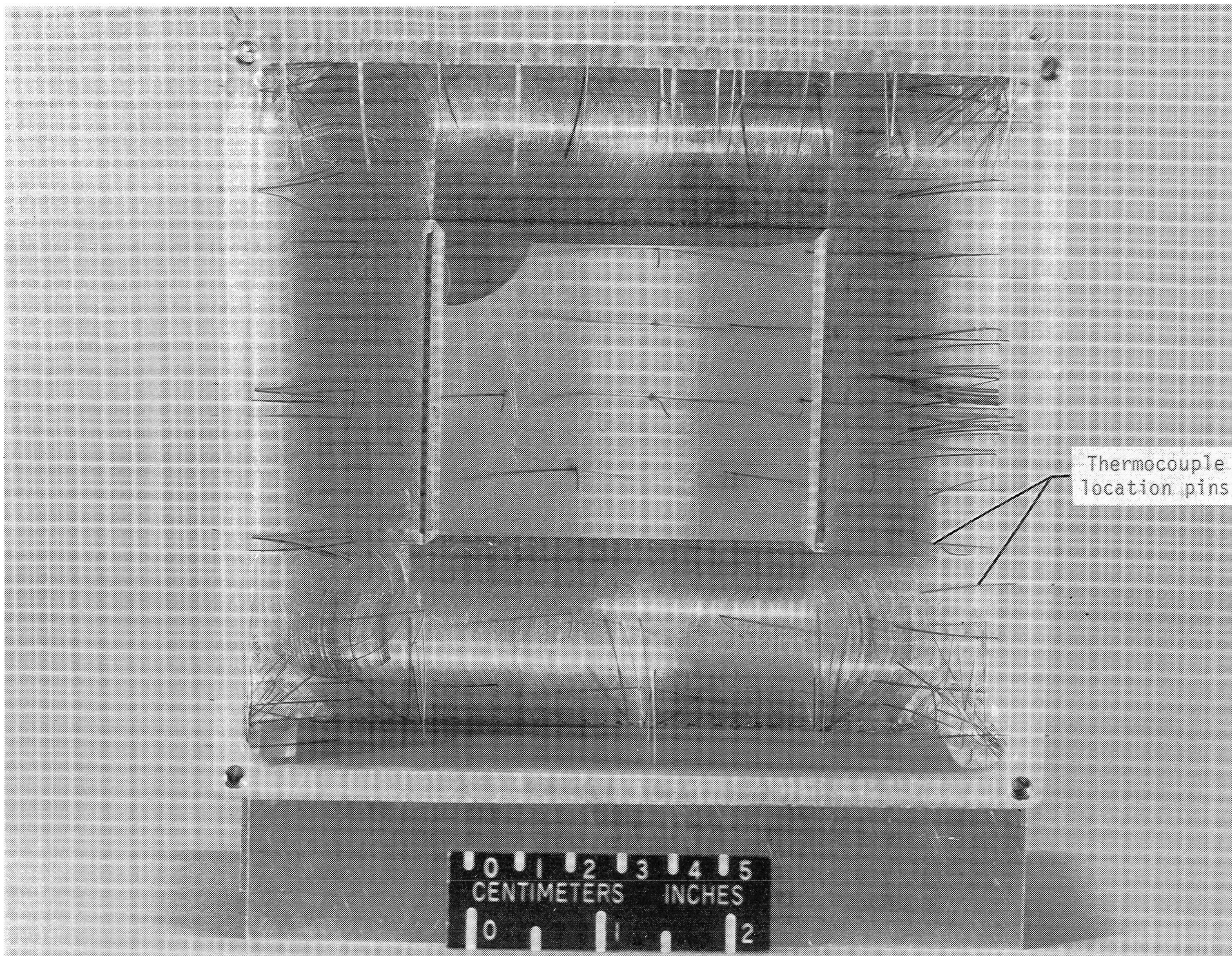
(b) Close-up of upstream corner.

Figure 5.- Continued.



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(c) Interior.

Figure 5.- Concluded.

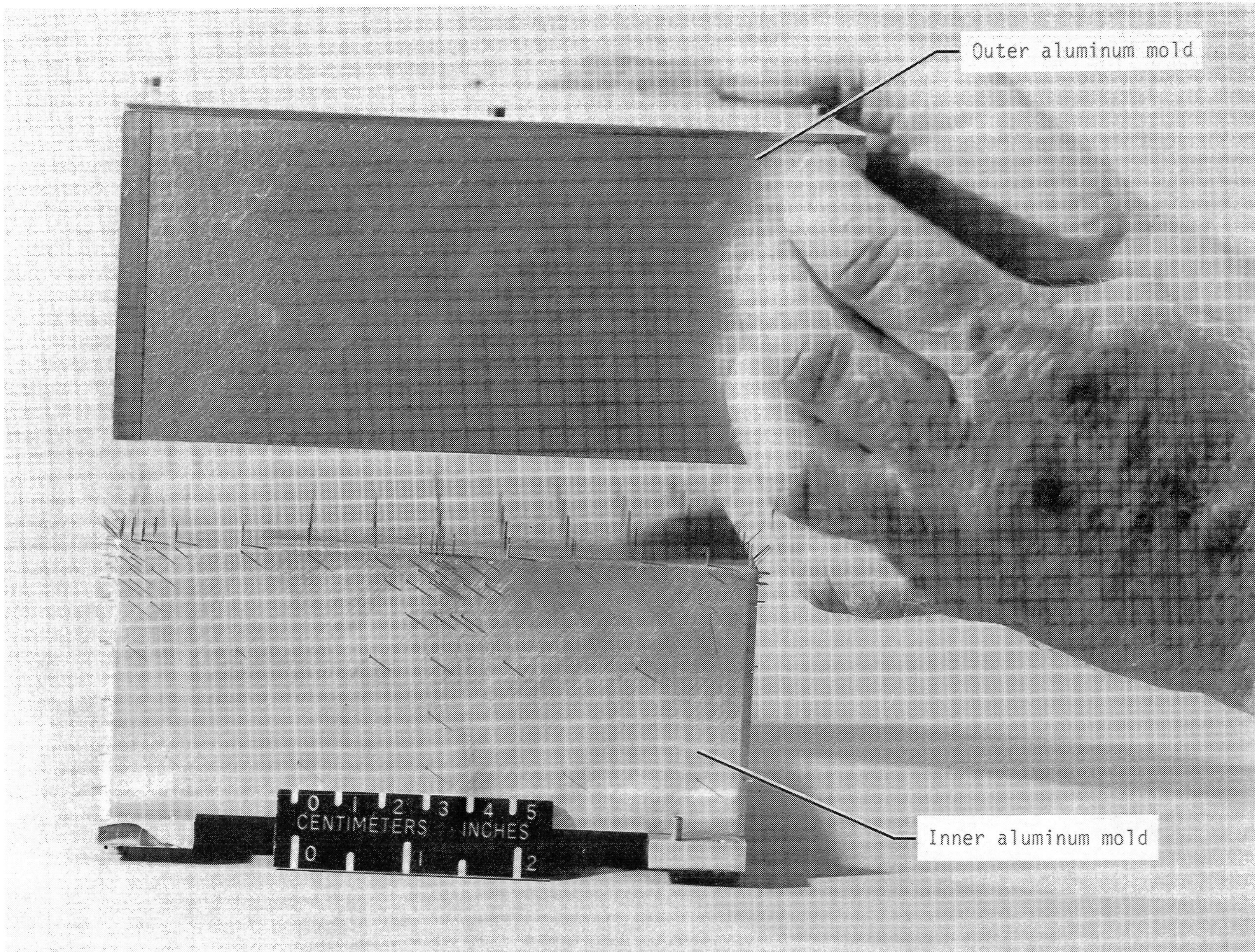

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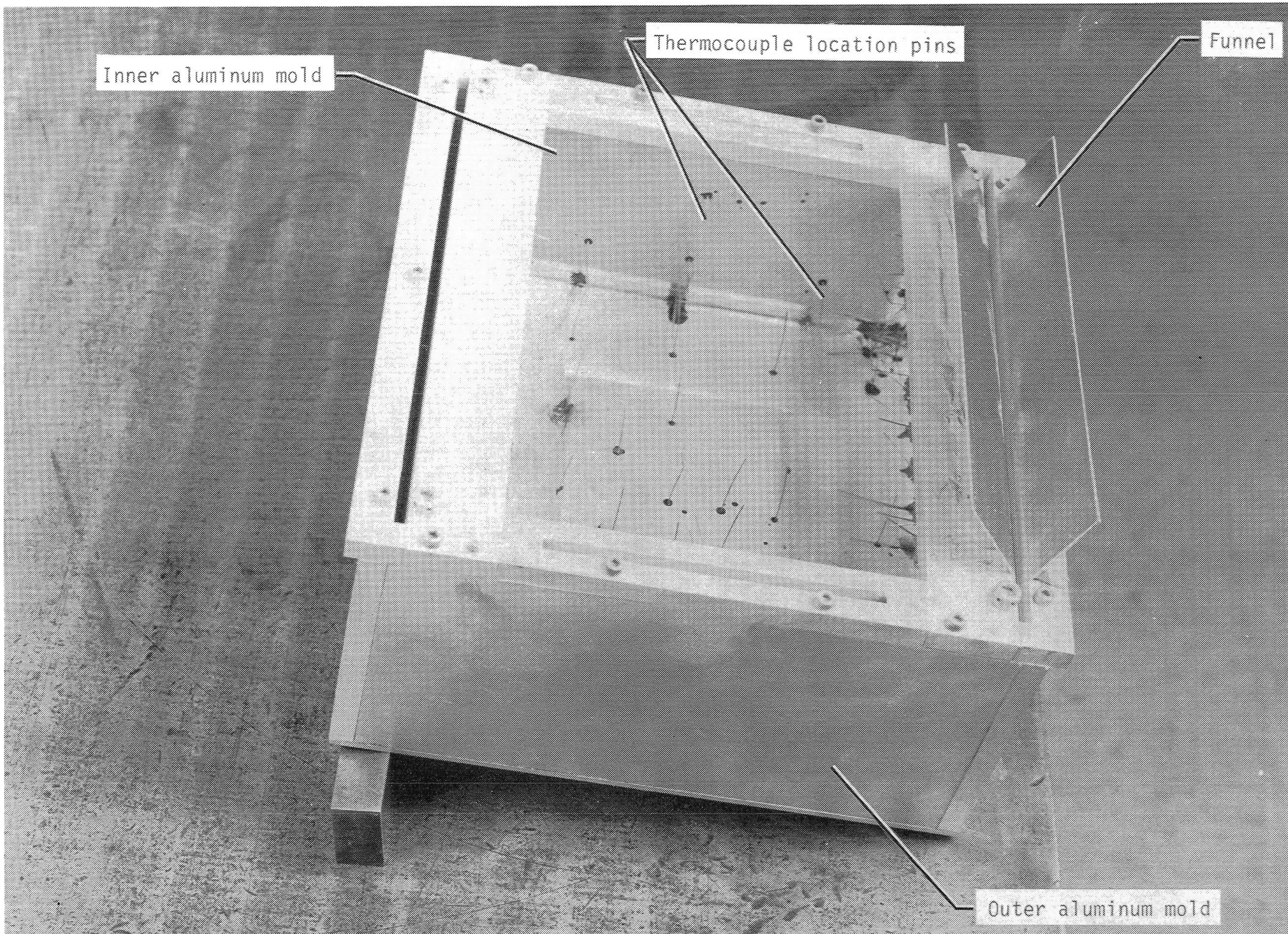
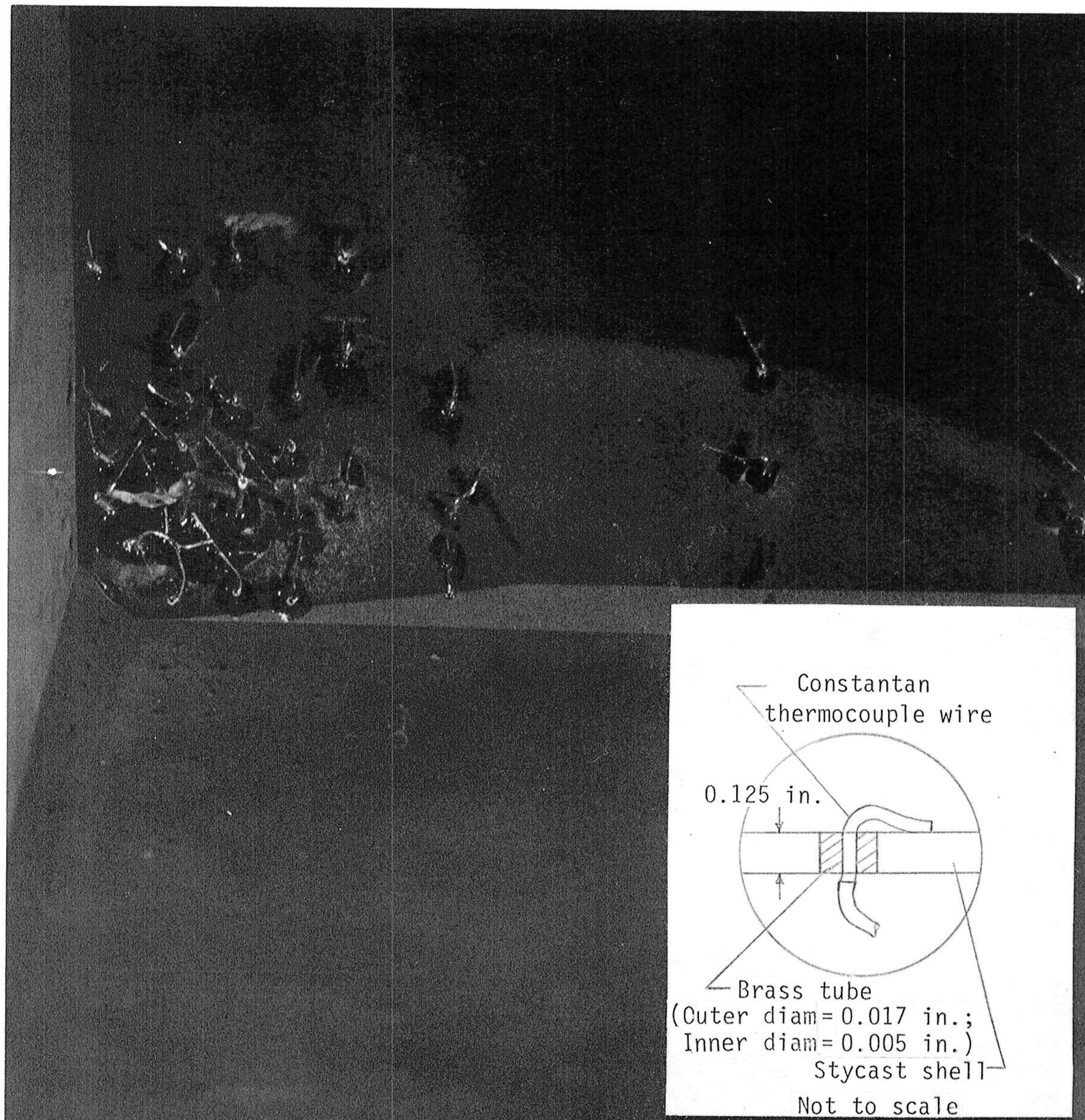
Figure 6.- Aluminum mold being assembled.



L-84-66

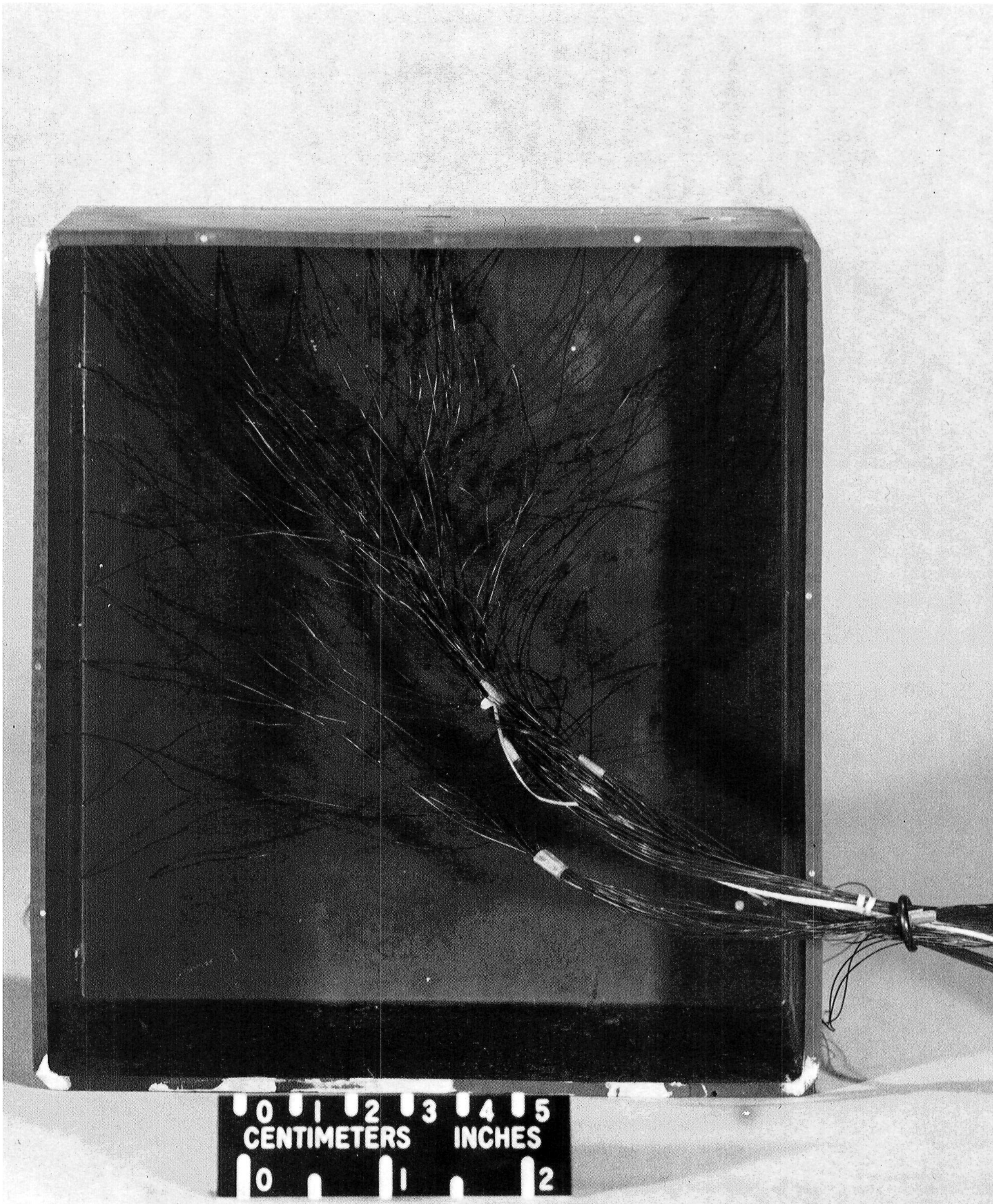
Figure 7.- Assembled aluminum mold.



L-84-67

(a) Close-up of upstream corner.

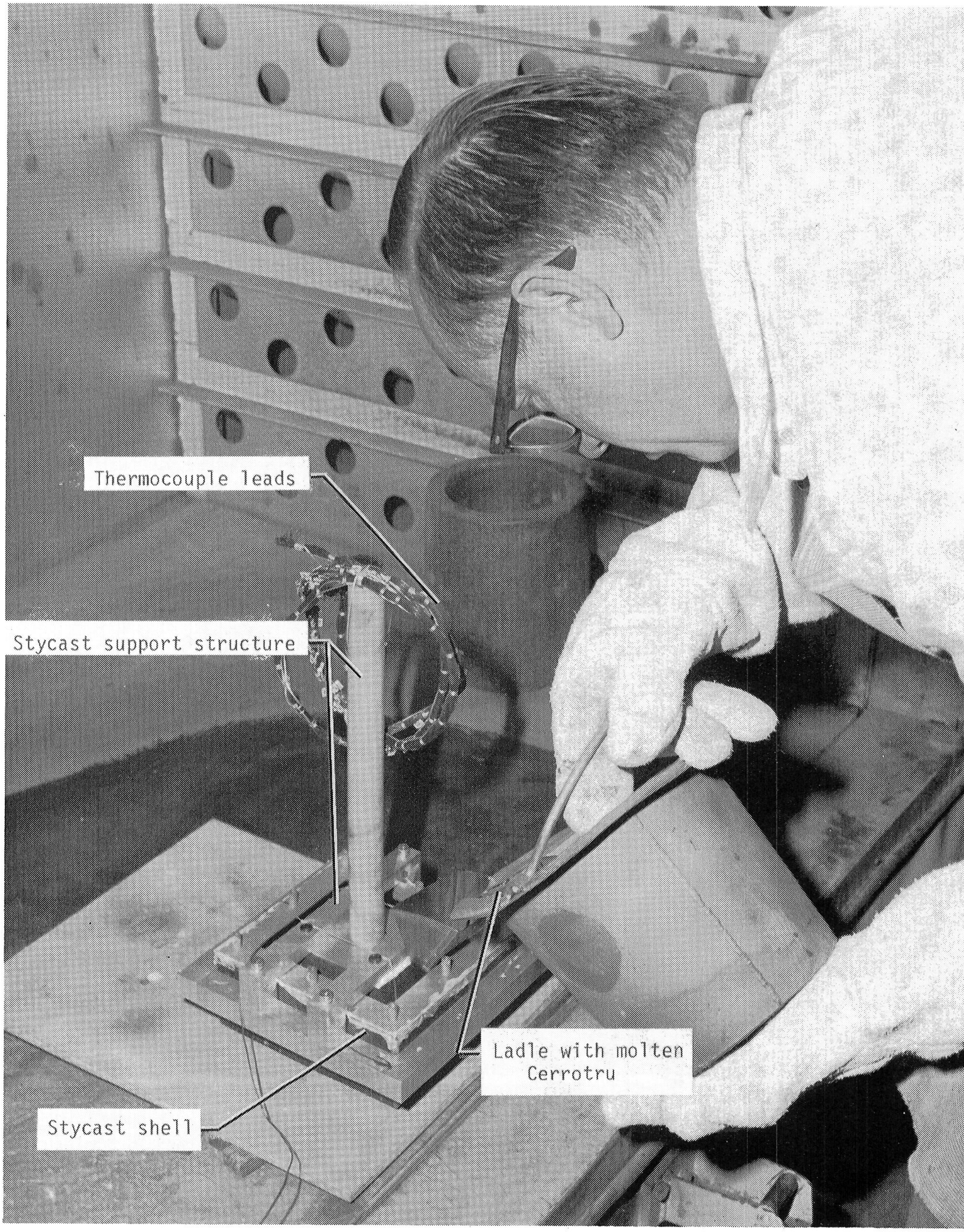
Figure 8.- Stycast shell partially instrumented.



L-84-68

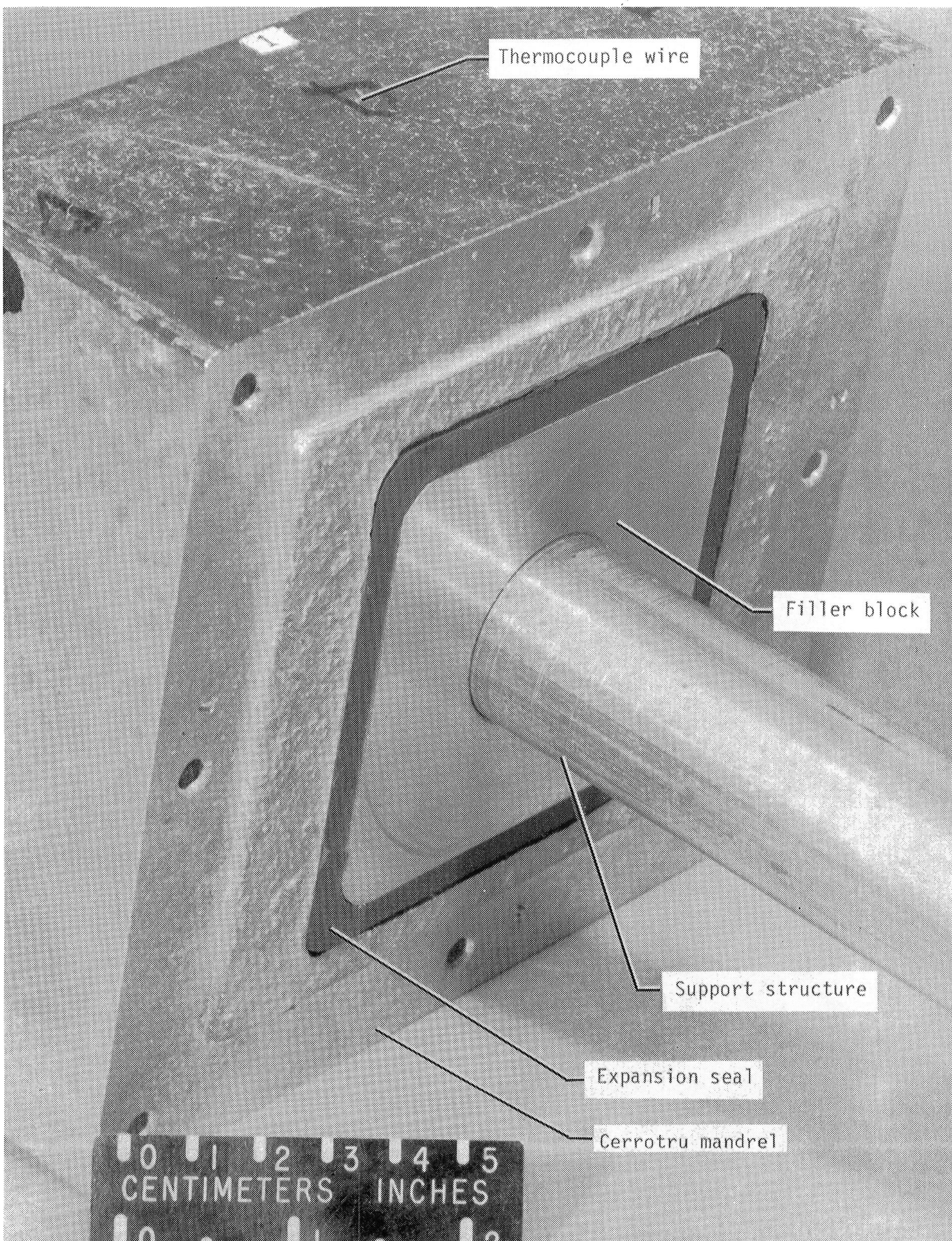
(b) Interior of Stycast shell.

Figure 8.- Concluded.



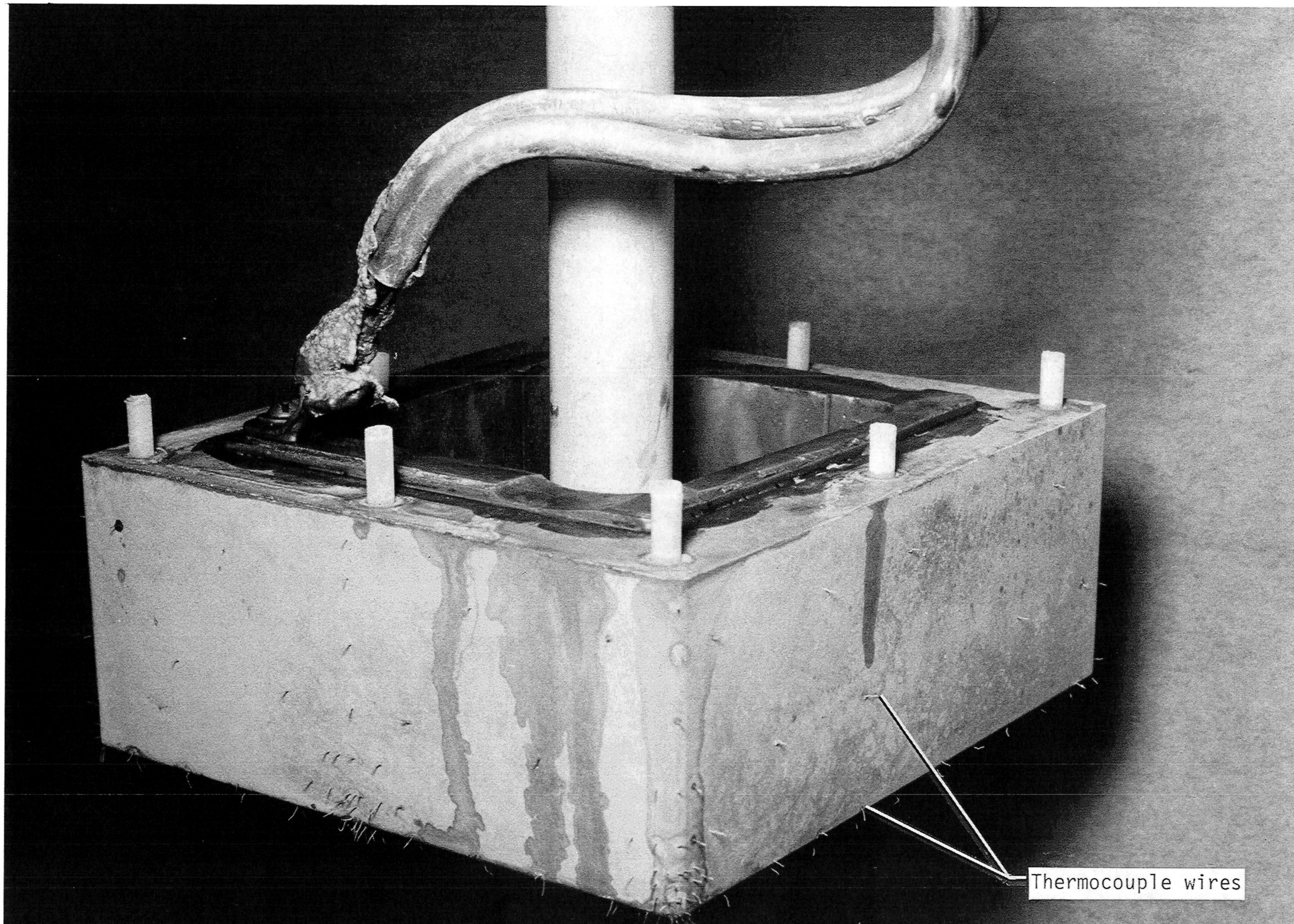
L-84-69

Figure 9.- Molten Cerrotru being poured into Stycast shell.



L-84-70

Figure 10.- Cerrotru mandrel with expansion seal and support structure.



L-84-71

Figure 11.- Cerrotru mandrel after copper strike.

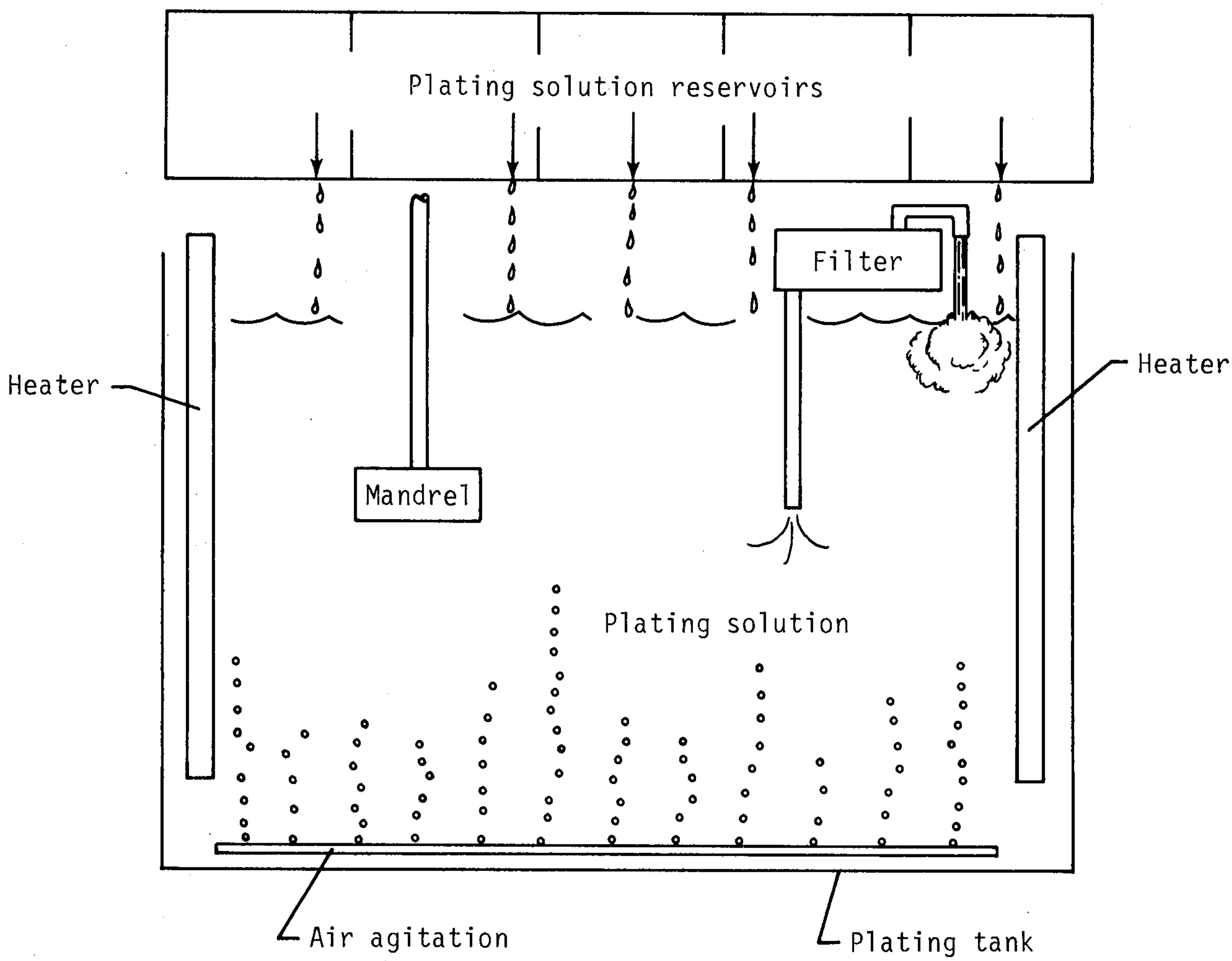
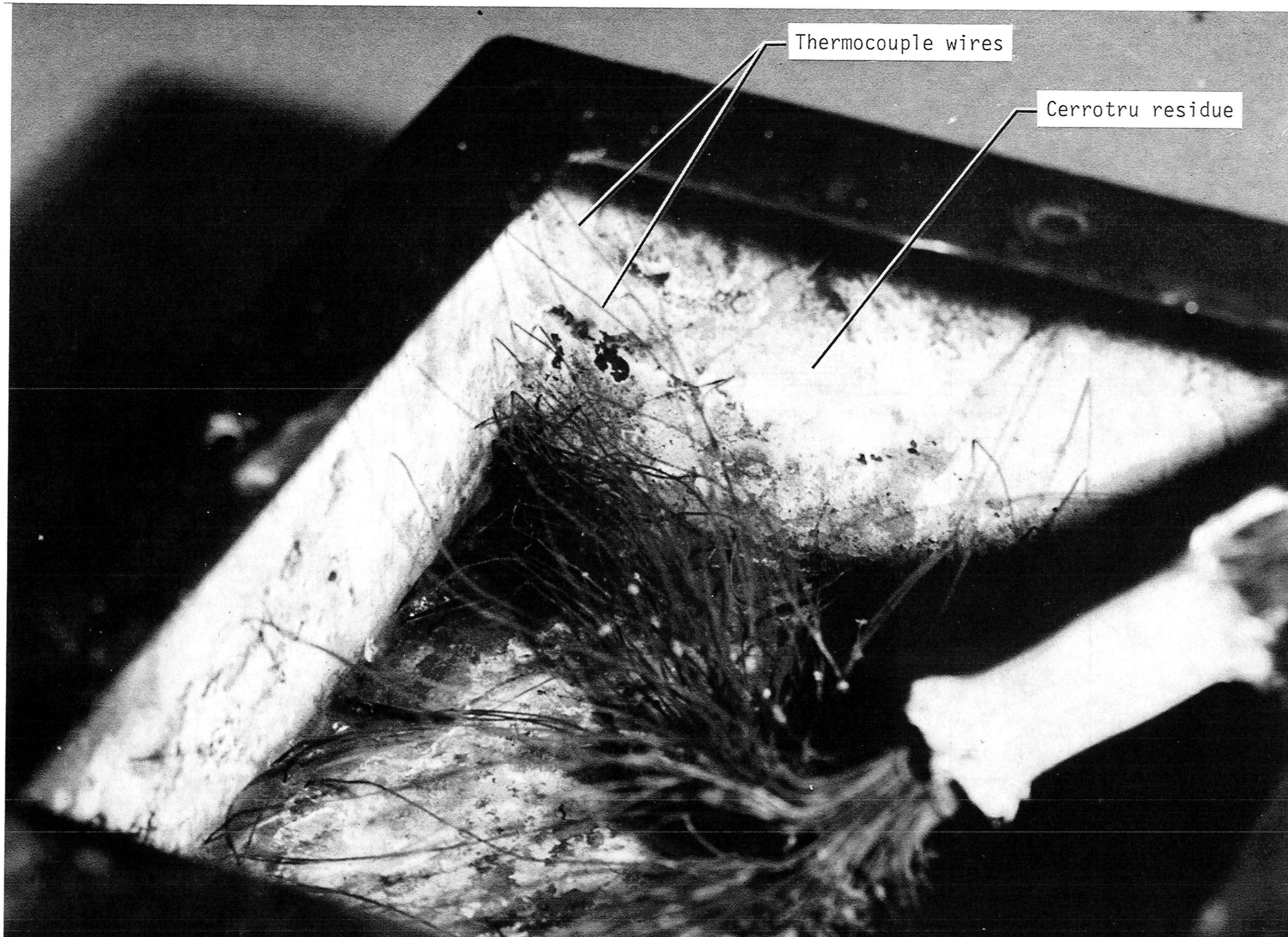
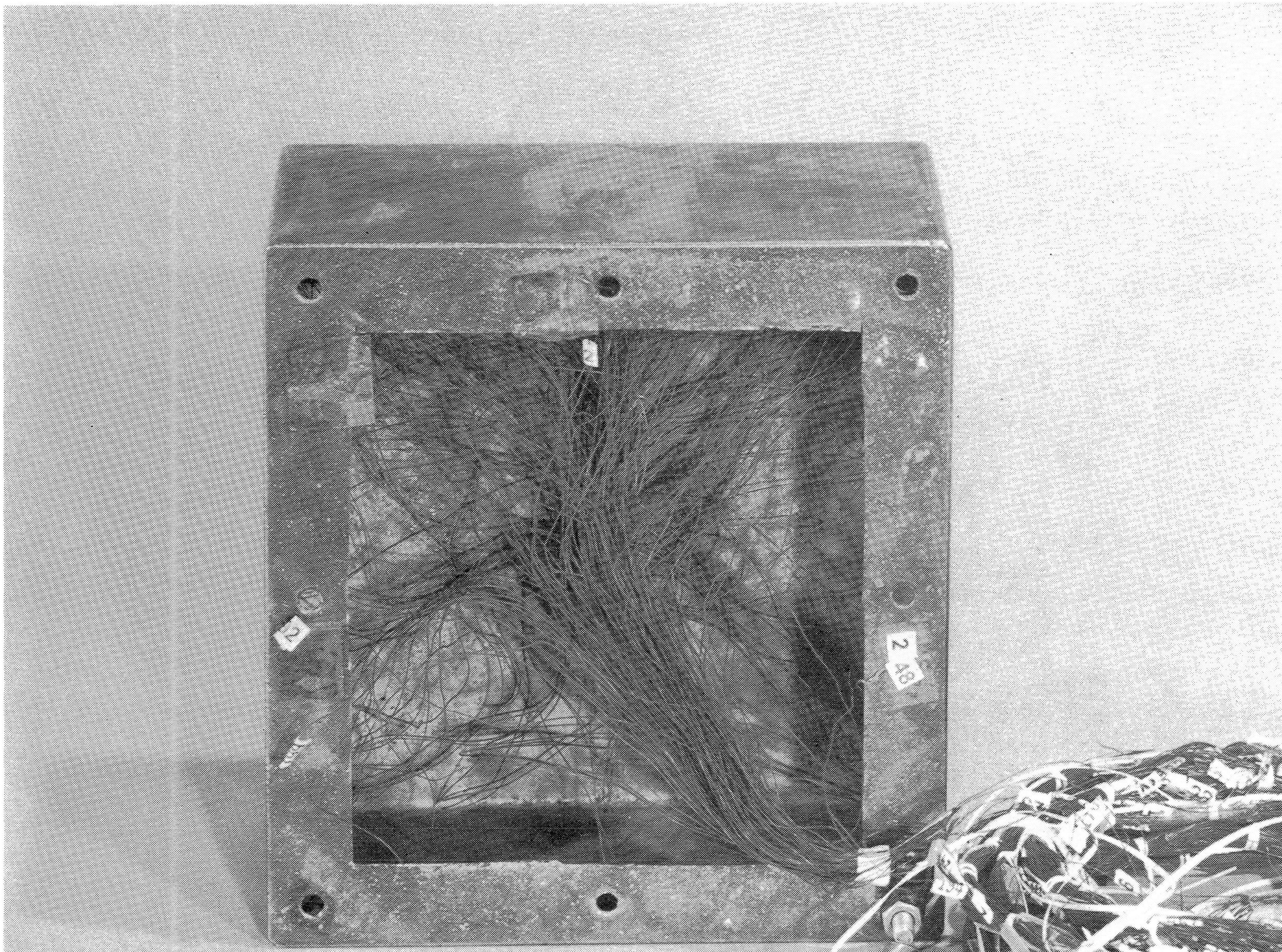


Figure 12.- Niculoy 22 electroless-plating tank and associated equipment.



L-84-72

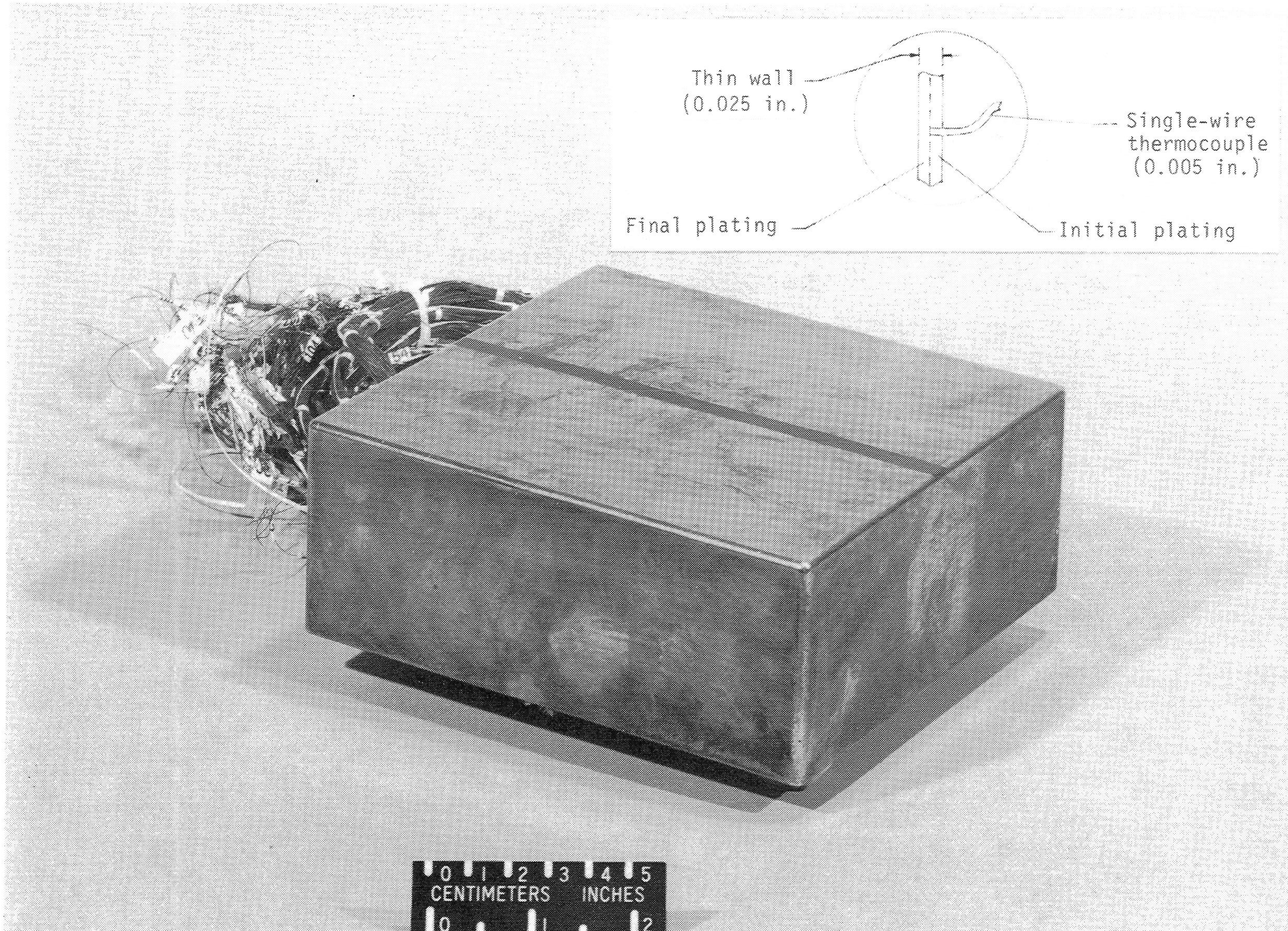
Figure 13.- Interior view of Niculoy 22 thin-wall tile after removal of Cerrotru mandrel by melting.



L-81-1356

(a) Bottom view.

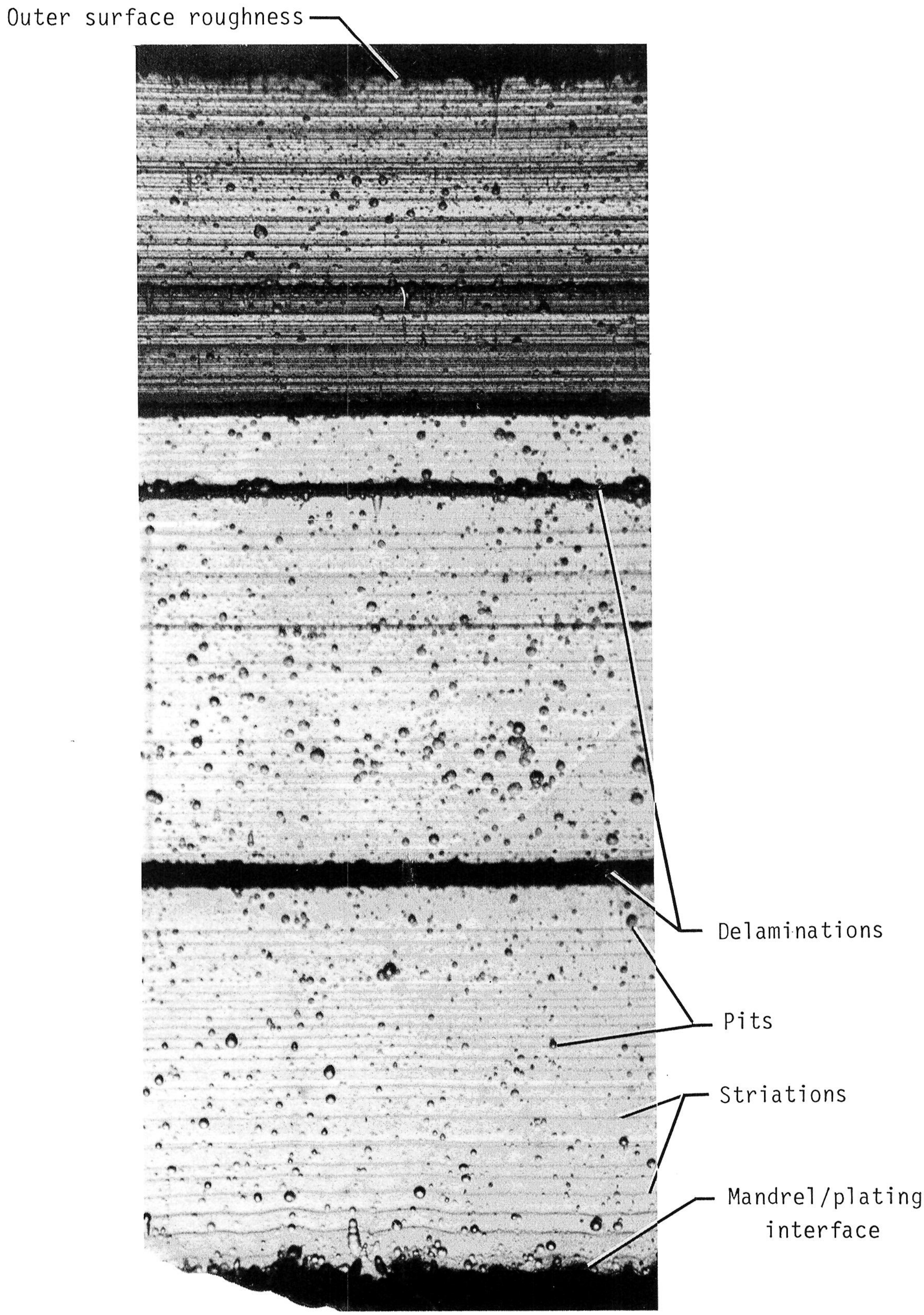
Figure 14.- Completed Niculoy 22 thin-wall tile.



L-84-73

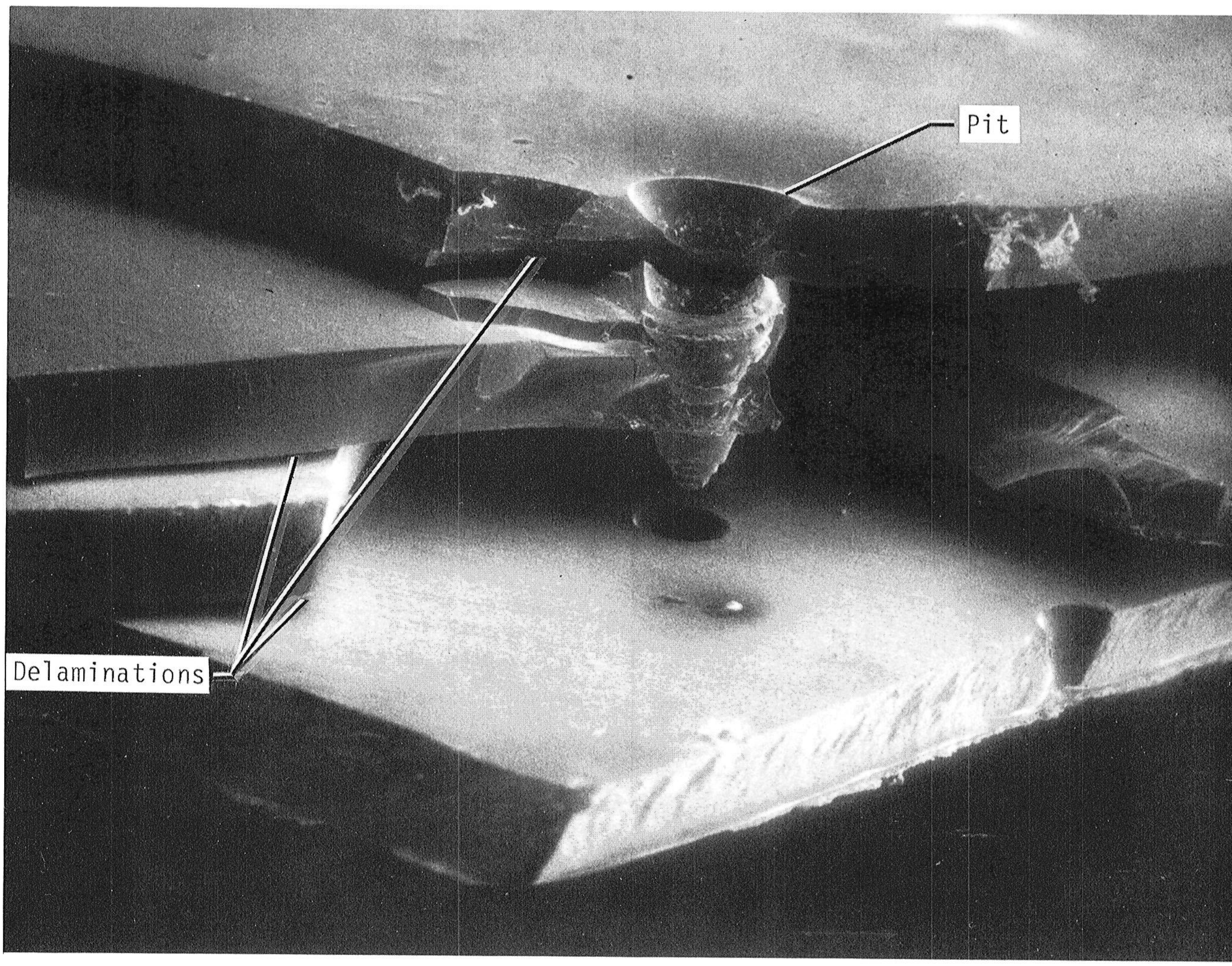
(b) Oblique view.

Figure 14.- Concluded.



L-84-74

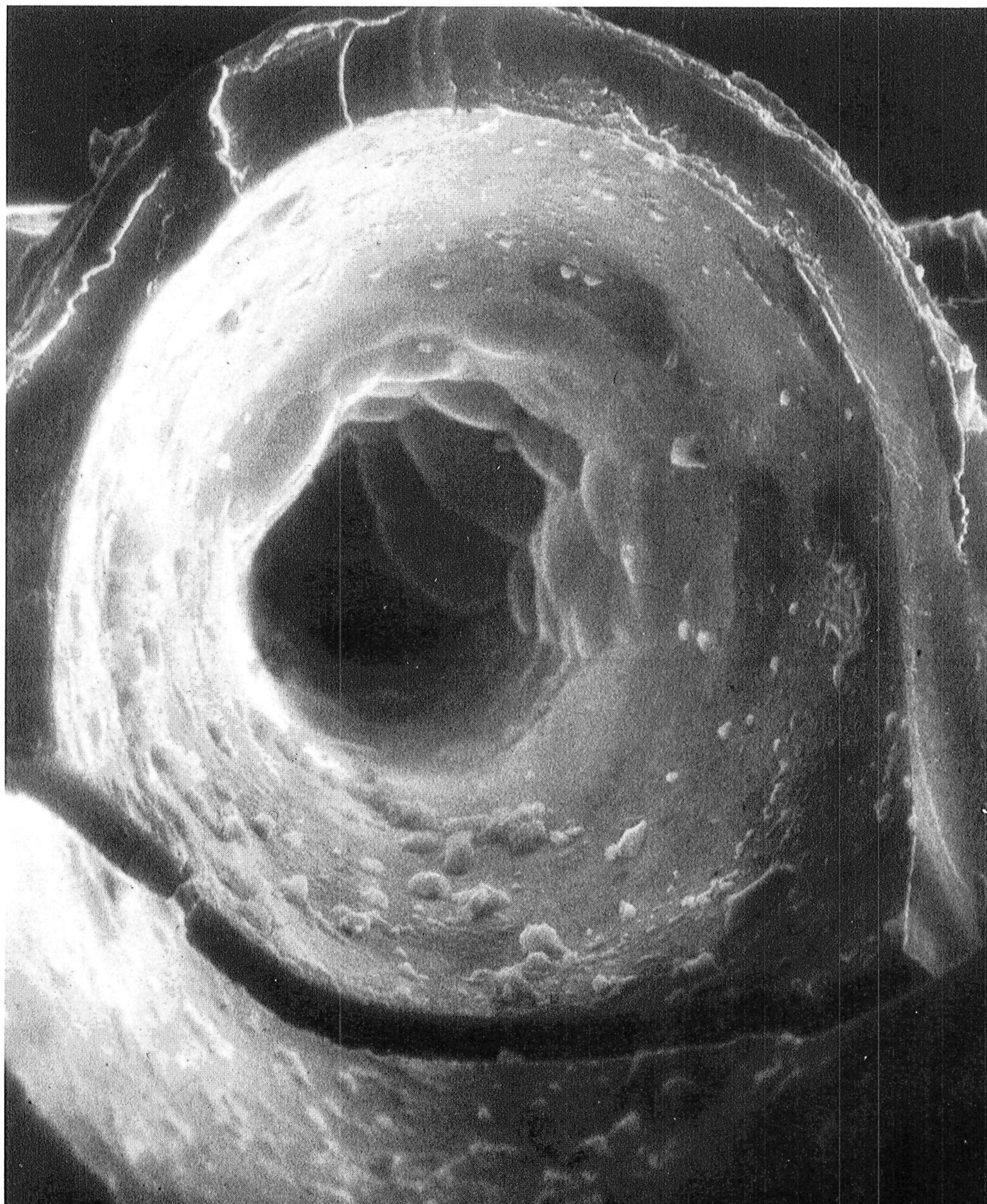
Figure 15.- Cross-sectional photomicrograph of defective plating sample (magnified 400 times).



L-84-75

(a) Side view (magnified 50 times).

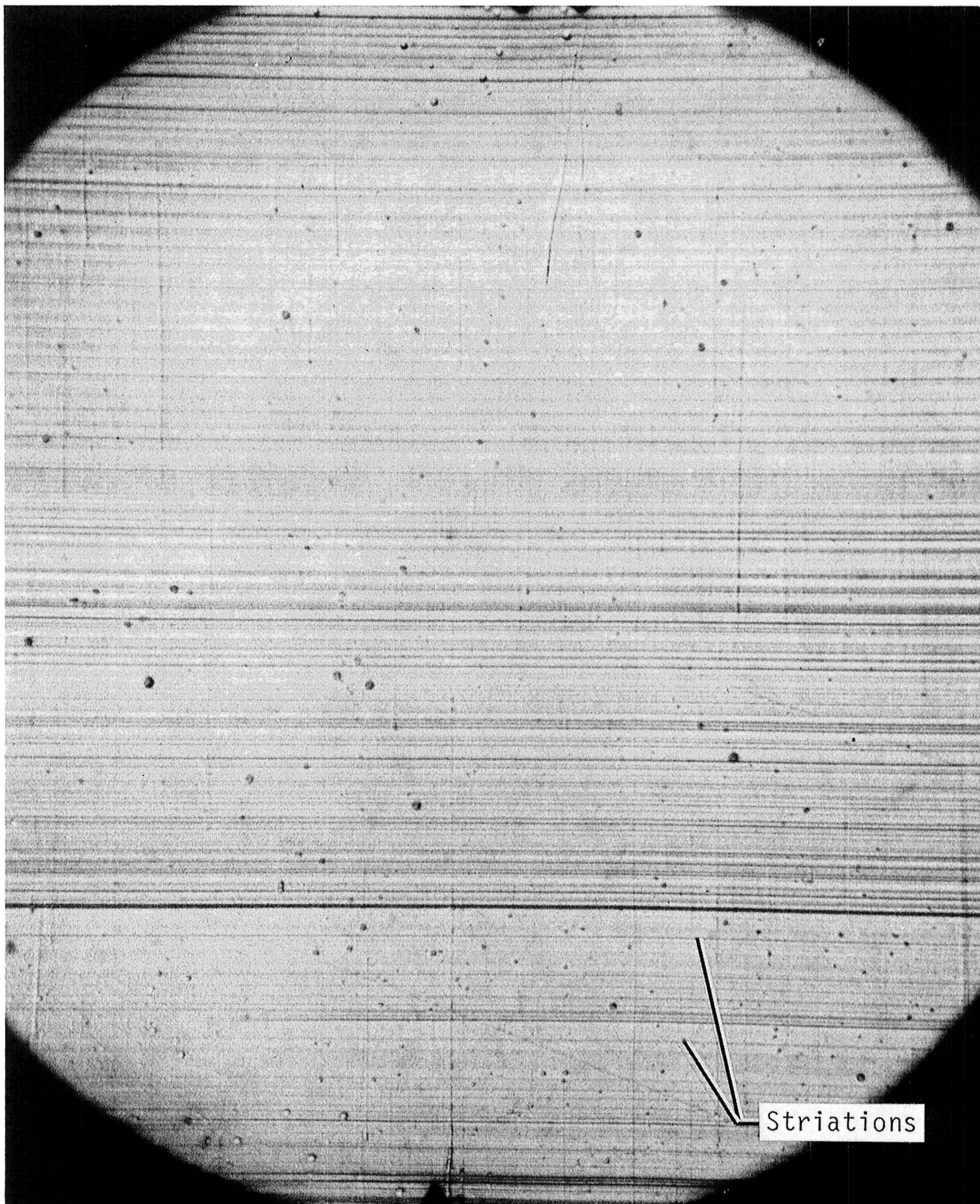
Figure 16.- Scanning electron microscopic close-up of pit and delaminations.



L-84-76

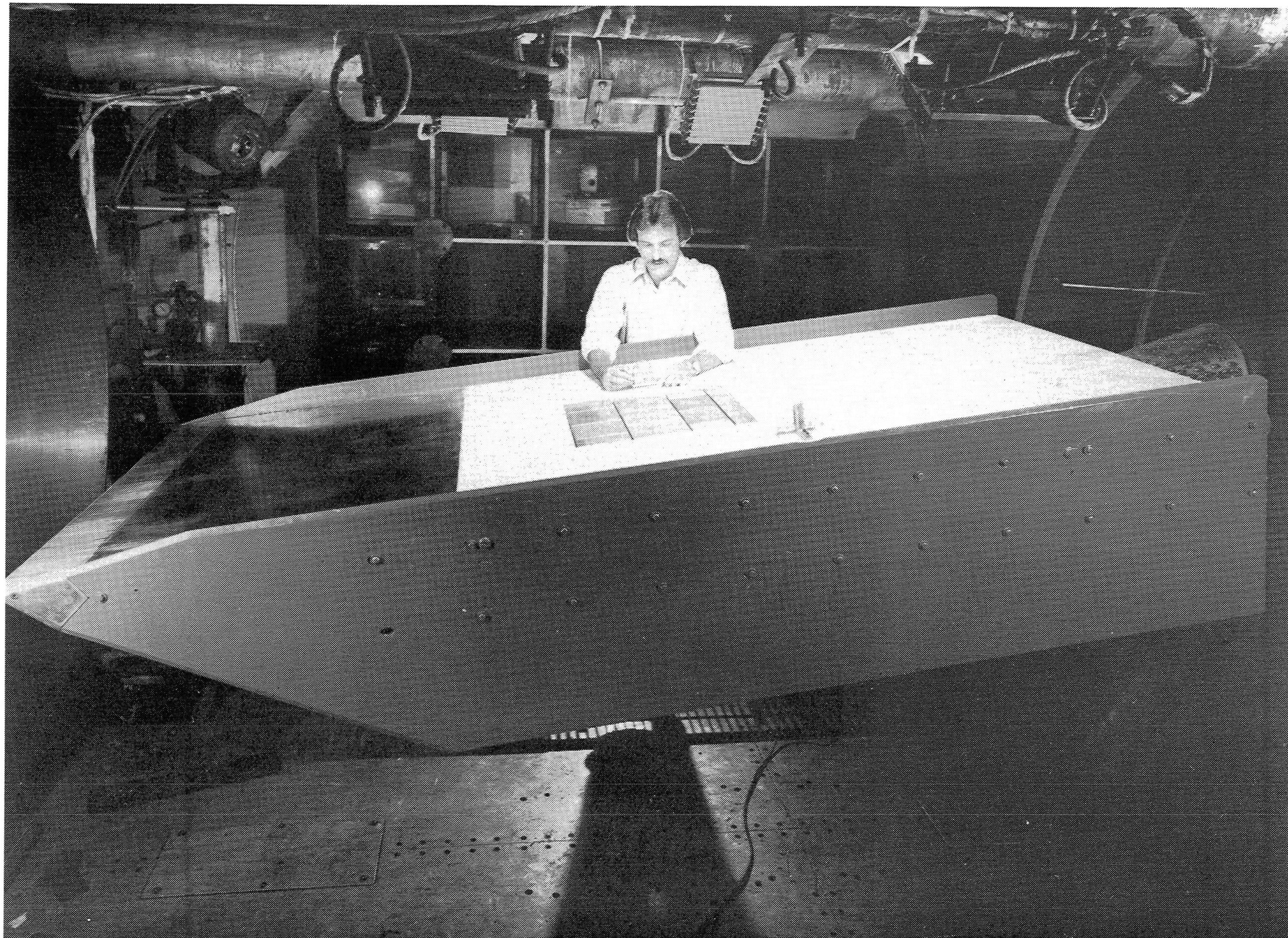
(b) Top view of pit (magnified 500 times).

Figure 16.- Concluded.



L-84-77

Figure 17.- Cross-sectional photomicrograph of successful plating sample (magnified 200 times).



L-81-6357

Figure 18.- Model installed in panel holder of Langley 8-Foot High-Temperature Tunnel.

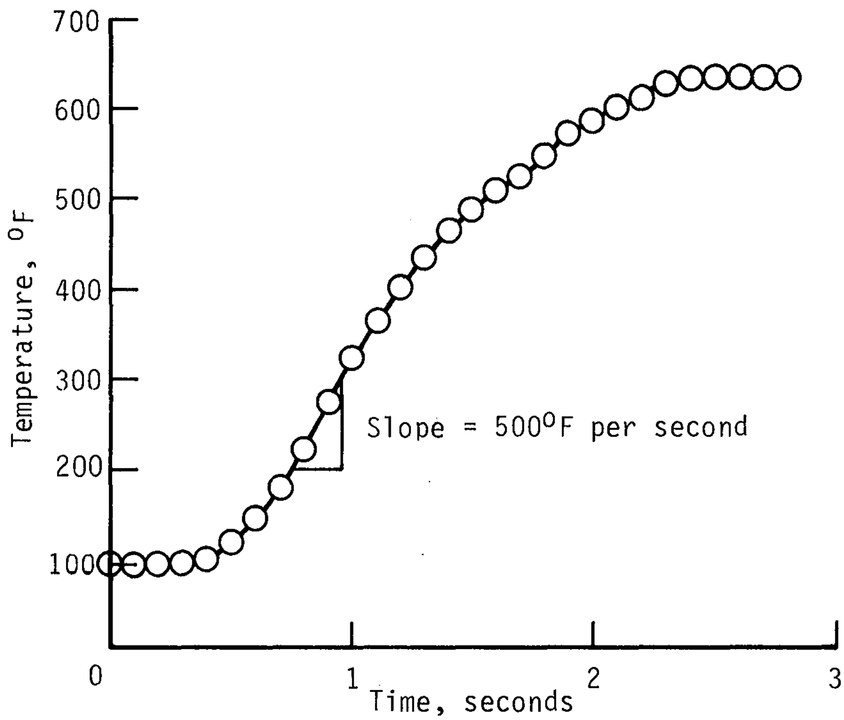
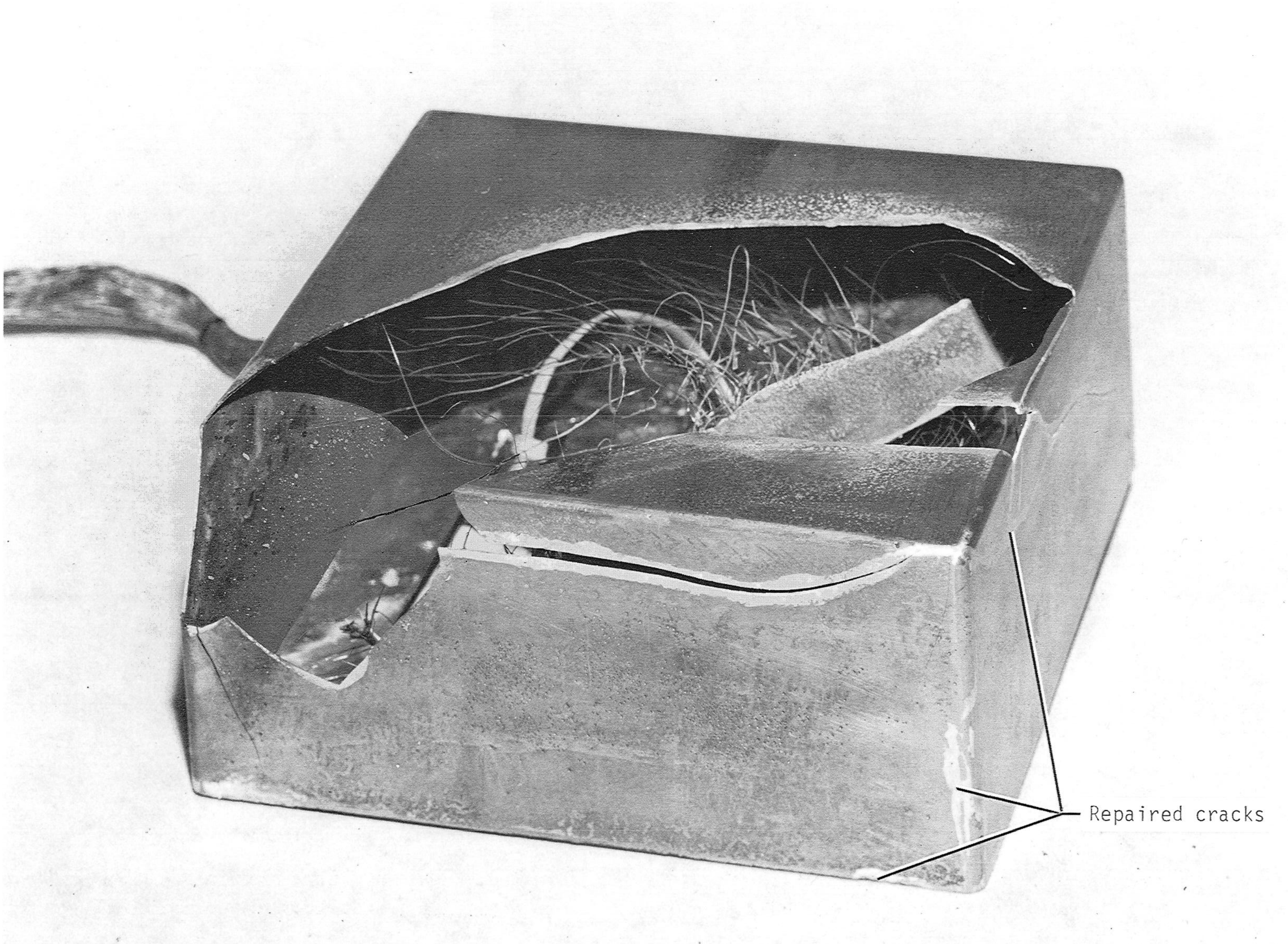


Figure 19.- Temperature history at location of tile failure.



L-84-78

Figure 20.- Thin-wall tile showing cracks and repaired cracks.

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16. Abstract

A new technique for fabricating uniform thin-wall metallic heat-transfer models is described. Two 6- by 6- by 2.5-in. tiles were fabricated to obtain local heat-transfer rates. The fabrication process is not limited to any particular geometry and results in a seamless thin-wall heat-transfer model which uses a one-wire thermocouple to obtain local "cold-wall" heat-transfer rates. The tile is relatively fragile because of the brittle nature of the material and the structural weakness of the flat-sided configuration; however, a method was developed and used for repairing a cracked tile.

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